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SILJA SUONIO

FORMATION AND ACTORS OF BIOGAS ECOSYSTEMS – THREE PLANNING PHASE CASES IN FINLAND

Master of Science Thesis

Examiners: Professor Jukka Rintala and doctoral student Maarit Särkilahti
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ABSTRACT

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Between the positive attributes of biogas, national and international goals for biogas promotion, and the current modest production and utilization rates, a clear discrepancy can be seen. Partly, this can be explained by small energy densities and scattered locations of biogas feedstock, which require especially careful planning in order to make a profitable production system. In addition to this, the end-use of the digestate needs to be planned. In order to create a complete cycle, a collaboration of multiple different actors, an industrial ecosystem, is typically required. These systems are unique and case specific, which makes creating them challenging.

In order to understand biogas ecosystems, their formation and actors were studied in this thesis. The thesis studied three promising biogas ecosystems located in central Finland that were in a planning or developing phase. Information was gathered primarily by focus group interviews, inviting possible actors from each case ecosystem in a group interview. The interview material was interpreted with the help of industrial ecosystem and socio-technical transition theories. The goal was to find out the drivers behind biogas ecosystem actors, recognize possible patterns for biogas ecosystem formation, and find other means for biogas ecosystem promotion.

Despite the differences between the researched ecosystems, surprisingly similar drivers behind the actors could be found. The most prominent driver in every ecosystem was environmental protection: emission reduction, nutrient recycling and water protection. Other recognized common drivers were ready gas infrastructure, increasing local production and reducing import dependency, and advancing technological development. No ready recipe for ecosystem formation could be found, which is in line with previous research. However, some elements for furthering the ecosystem formation were recognized: suitable location and land use planning, similar values and goals of different actors, and an active system builder that progresses the project and inspires other actors. In addition to these findings, it was noted that shielding measures for biogas should be recreated: the current shielding measures should be made more flexible, and the shielding measures should be targeted more diversely towards different aspects of the technological regime.

TIIVISTELMÄ

SILJA SUONIO: Biokaasuekosysteemien muodostuminen ja toimijat – kolme suunnitteluvaiheessa olevaa esimerkkiekosysteemiä Suomessa
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Biokaasun positiivisten ominaisuuksien, kansallisten ja kansainvälisten tuotantotavoitteiden ja vaatimattoman hyödyntämisasteen välillä on selkeä ristiriita. Osin tätä selittää se, että biokaasun tuotantoon liittyvät materiaalivirtojen energiatiheydet ovat suhteellisen pieniä ja syötemateriaalien sijainti hajanainen, minkä takia kaasuntuotantoprosessin kannattavaksi saaminen vaatii huolellista suunnittelua. Haastavuutta lisää myös se, että kaasun lisäksi loppukäyttö täytyy suunnitella myös mädätysjäännökselle. Jotta kokonaisuus saadaan toimimaan, tarvitaan usein monen toimijan muodostama yhteenliittymä, teollinen ekosysteemi. Nämä systeemit ovat ainutlaatuisia ja tapauskohtaisia, mikä tekee niiden suunnittelusta haastavaa.

Biokaasuekosysteemien muodostumista tutkimalla niitä voitaisiin kuitenkin ymmärtää paremmin, ja siksi tässä työssä on kartoitettu systeemien muodostumisedellytyksiä ja systeemien toimijoita motivoivia tekijöitä. Tietoa kerättiin kolmesta Keski-Suomessa sijaitsevasta kehitysvaiheessa olevasta biokaasuekosysteemistä pääasiassa ryhmähaastattelujen avulla. Jokaisessa ryhmähaastattelussa oli saman biokaasusysteemin toimijoita mahdollisimman laajasti. Haastattelumateriaalia tulkittiin teollisten ekosysteemien teorian ja sosioteknisten transitioiden teorian avulla. Aineiston ja teorian avulla pyrittiin selvittämään, mitkä asiat motivoivat eri toimijoita biokaasun tuotantoon, millä tavoin ekosysteemit muodostuvat, ja kuinka niiden muodostumista voisi edistää.

Tutkittujen ekosysteemien erilaisuudesta huolimatta toimijoiden ajurit eri systeemeissä olivat huomattavan samanlaisia: tärkeimmäksi ajuriksi nousi ympäristönsuojelu – päästöjen vähentäminen, ravinnekierron parantaminen ja vesistöjen suojelu. Muita tunnistettuja ajureita olivat valmis kaasuinfrastruktuuri, paikallisen tuotannon lisääminen ja tuonnin vähentäminen sekä teknologisen kehityksen edistäminen. Ekosysteemien muodostamiselle ei löydetty varsinaista ohjetta, mikä tukee aikaisempaa tutkimusta. Tutkimuksessa löydettiin kuitenkin tekijöitä, jotka edesauttavat systeemien muodostumista: systeemille sopiva kaavoitus ja sijainti, toimijoiden samanlainen arvomaailma ja tavoitteet, sekä aktiivinen systeeminrakentaja, joka innostaa muita toimijoita ja edistää projektia. Näiden lisäksi havaittiin, että biokaasua edistävät tukitoimet täytyisi suunnitella paremmin: olemassa olevia tukitoimia tulisi muokata joustavammiksi, ja tukitoimia tulisi myös kohdentaa huomattavasti nykyistä laaja-alaisemmin.

PREFACE

This thesis was funded by Gasum Oy and written in Tampere University of Technology, with the main goal of increasing the understanding of biogas ecosystem formation. I would like to thank Gasum for enabling the project, and especially Mari Tuomaala and Esa Parkko, from the fascinating research topic and their invaluable advice and support throughout the process.

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Silja Suonio

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

AD	Anaerobic Digestion
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CSTR	Continuously-Stirred Tank Reactor
ELY-Center	Centre for Economic Development, Transport and Environment
EU	European Union
GHG	Greenhouse Gas
IE	Industrial Ecology
LNG	Liquefied Natural Gas
MSW	Municipal Solid Waste
MTK	The Central Union of Agricultural Producers and Forest Owners
MWW	Municipal Wastewater
Nm^3n	Normal cubic meter; one cubic meter of gas in the atmospheric pressure and temperature (ISO2533)
Bio-SNG	Synthetic Natural Gas – biogas made from organic matter but without anaerobic digestion; e.g. wood gasification
ST-regime	Socio-Technical regime
ST-transition	Socio-Technical transition

1. INTRODUCTION

Both the global warming, and the decreasing reserves of fossil raw materials such as coal, oil and fossil fertilizers, are sending us a clear message: alternatives are needed. Estimates for the reserve sufficiency are varied: world's oil and natural gas reserves are assessed to last for 40-70 years, and coal for 107-200 years (Shafiee & Topal, 2009). The greenhouse gas (GHG) emissions the utilization of these energy sources produce suggest that alternatives should be found, even before complete depletion of the reserves. (Panwar et al., 2011) There are different estimates for phosphate rock reserves, which are used as fertilizers. Bouwman et al. (2009) suggests that by 2100, 36-64% of fossil fertilizer reserves will be depleted. With the fertilizers, there is also concern for eutrophication they may cause if they end up in the water system. (Bouwman et al., 2009)

No one solution will solve the multiple challenges at hand. Instead, a comprehensive rethinking of energy systems is needed, and the solution will most probably be some kind of combination of sustainable solutions. (Panwar et al., 2011) Biogas production is one promising element: biogas production and utilization address both the fossil fuel and fossil fertilizer challenge, and have various positive qualities, in addition to this. First of all, the fractions used as feedstock in anaerobic digestion (AD) process – such as animal manure, organic municipal solid waste, or crop residue - are generally considered waste. The biogas production process reduces the volume and odour of the feedstock, reduces harmful pathogens, and makes the nutrients in the feedstock more easily absorbable. The process produces renewable gas and digestate, which can be used as a renewable fertilizer. The produced gas is storable, and a versatile fuel, as it can be used for heat and electricity production, and it also works as a vehicle fuel after purification. And if the gas replaces fossil fuels, it reduces overall emissions. The flexibility and adaptability of the technology also mean that it can be tailored to different locations and circumstances. (Abbasi et al., 2012)

Both European Union (EU) and Finland have seen the potential biogas holds, and encouraged its production with several incentives and requirements. For example, EU has created a directive for clean vehicle fuel infrastructure that obligates the member countries to have an extensive gas fueling network by 2020 (2014/94/EU). Finland has different kinds of investment supports for different types of production units, and alternately, the producer may receive feed-in tariff from electricity that is produced from biogas. In 2015, implementation plan of the Finnish Government Programme was released - and one of the five strategic priorities in the program is "Bioeconomy and clean solutions". (Valtioneuvosto, 2016). Especially the first and third key projects and their funds – *"Towards carbon-free, clean and renewable energy cost-efficiently"* and *"Breakthrough of* *a circular economy, getting waters into good condition"* can directly support biogas projects. In addition to the environmental effects, the Finnish biogas potential also holds considerable economical potential (Mutikainen et al., 2016). One could imagine that this, together with the incentives, would speed up biogas production. The Government Programme and its key projects are so recent that their effect is not yet visible – but at least the previous goals Finland has set for biogas production are rather far from actualizing (Huttunen & Kuittinen, 2011; KTM 5/2003).

This study investigates the discrepancy between extensive incentives and the modest production rate. Biogas technology has advanced considerably in the last few decades (Wellinger et al., 2013), but a lot needs to be done. Biogas research indicates (Ollson & Fallde 2015) that means to promoting biogas more efficiently could be found by investigating biogas systems from a broader perspective. Biogas has a tendency of forming unique, multi-field collaborations, which makes planning or implementing these systems difficult. (Olsson & Fallde 2015) Researching actors, forming methods and drivers behind ecosystems could help understanding them better, and thus, help finding methods for their promotion. The first research question thus concentrates on the formation and actors of these ecosystems: can there be found similarities or patterns in the biogas ecosystem formation? And are there similar drivers in different kind of ecosystems and their different actors? Can there be found means for biogas ecosystem promotion? In addition to this, the research aims to find out whether an existing biogas "core" – such as gas pipeline or larger biogas production unit – affects the formation of smaller, decentralized satellite ecosystems that could utilize the backup opportunity the core offers.

First, the theoretical background relevant for the thesis is discussed: AD technologies and feedstock, products and utilization of AD process products are covered briefly. As greenhouse gas emission reduction is a powerful driver for increasing biogas production, a small example calculation of emission reduction potential of biogas is also presented. Then, natural gas and Finnish gas infrastructure are discussed, as natural gas has many same uses as biogas, and biogas can utilize the ready gas infrastructure. To better understand the systems forming around biogas production, the concepts of socio-technical transitions, industrial ecology and industrial ecosystems are presented, and some examples of biogas ecosystems are discussed. The theory chapter also takes an overview on Finnish biogas production targets, current incentives and production rates. Research methodology presents the three studied case ecosystems and the primary data collection method – focus group interview – that was used. Finally, the answers to the research questions are presented.

2. THEORETICAL BACKGROUND

In this chapter, the theoretical background of this thesis is introduced. The theory begins with a brief overview of biogas production and utilization. As gas infrastructure affects the storage and distribution possibilities of biogas, its current coverage in Finland is observed. The biogas ecosystem formation is approached via socio-technical transition theory and industrial ecosystem theory. Finally, the formation and functioning of biogas ecosystems are viewed.

2.1 Biogas technology overview

The following chapters give an introduction to biogas technology. The principles of AD are described, as well as the major feedstock types, biogas production outputs and their utilization possibilities.

2.1.1 Anaerobic digestion technologies

Biogas is produced through AD of organic matter. Depending on the feedstock used for AD, the forming biogas typically consists of 50-75% methane (CH_4), 25-50% carbon dioxide (CO_2), and small amounts of other gases (e.g. hydrogen (H_2), nitrogen (N_2), oxygen (O_2) and hydrogen sulfide (H_2S)). Because of the high methane content, biogas has good calorific value and several different utilization possibilities. (Wellinger et al., 2013)

The biogas production may occur naturally, e.g. in landfill sites, as the micro-organisms causing AD are quite common. However, in controlled environment, biogas production is much more efficient. The optimal conditions depend on the used feedstock, but steady conditions are vital for AD: temperature and pH should be suitable and steady, and the lack of oxygen is essential. Other than that, there are several different variables how the process can differ: the amount of process steps, the texture of the feedstock, and the method of adding the feedstock to the digester, for example. The process optimization is important; not only to reach optimal biogas amount and content, but to minimize the methane leakage from the leftover digestate, as methane's global warming potential is 25 times that of carbon dioxide's. Choosing the right temperature and time for digestion also ensures that harmful pathogens are destroyed, and the digestate is safe to utilize. (Abbasi et al., 2012; Wellinger et al., 2013)

The digestion unit itself contains various different alternatives for process optimization. The feedstock **feeding system** depends on the quality of the feedstock and the digester type. For continuously stirred –tank reactors (CSTR), the feeding system must be continuous or semi-continuous. Whereas, for batch digesters, the feeding system is discontinuous. Solid and liquid substrates also have different kind of requirements for the feeding system. The **reactor type** choice primarily depends on the dry matter content of the feedstock. CSTR may be used for liquid substrates, but solid substrates require plug-flow or batch digester. CSTR naturally requires more energy, but also improves the methane production. CSTR is the most common reactor type, representing 90% of the current biogas reactors worldwide. (Wellinger et al., 2013)

Feedstock stirring is important, as it distributes the heat, micro-organisms and substrates evenly in the material, and helps the gas bubbles to escape. There are also several different options when choosing the **agitation system**, and the quality of the agitation system depends on the dry matter content of the feedstock. High solids concentration in the feedstock requires mechanical agitators; in other words, propellers or paddles. The mechanical systems are also suitable for feedstock with low solids concentration, but their weakness is abrasion and the difficulty of maintenance. With liquid substrates, hydraulic or pneumatic agitation systems are an option, in addition to the mechanical one. (Abbasi et al., 2012)

The desired **reactor temperature** also needs to be chosen based on the used feedstock. If there is no risk of the feedstock containing harmful pathogens, mesophilic temperature (25-45°C) is typically chosen. If the feedstock requires pathogen inactivation, like in the case of organic household waste, thermophilic temperature area (50-58°C) is a safer choice; especially if the sanitation is not included in the pre-treatment. (Wellinger et al., 2013) For field application, digestate hygienisation is especially crucial, which is why a separate heat treatment (e.g. 70°C for 1 hour) is typically used in Finland to ensure the pathogen removal. (Kymäläinen & Pakarinen, 2015) Among the sanitation, temperature affects other features; higher temperatures speed up the degradation process, which results in shorter retention times and smaller reactor volumes. However, maintaining higher temperature naturally requires more energy, and with higher temperatures, process requires even higher stability in temperature and pH. There are also digesters without heating systems, where the temperature naturally settles between 10°C and 25°C. In these psychrophilic reactors, the retention time is even longer than in mesophilic, and they are mainly used in developing countries. Mesophilic reactors are the most common reactor type, representing 90% of the current biogas reactors in the world. (Abbasi et al., 2012; Wellinger et al., 2013)

While most biogas production units only use one phase, it is possible to increase the **number of phases**. Dividing the different phases of degradation to separate tanks enables creating optimal circumstances (pH, temperature and retention time) for each phase. The four stages of degradation (hydrolysis, acidogenesis, acetogenesis and methanogenesis) are caused by different bacteria, and for them, optimal circumstances are different. But obviously, increasing the number of phases increases investments costs, which partly explains the popularity of one-phase digester. The feedstock used determines yet again whether using multiple phases is necessary - or profitable. With high content of sugar, starch or proteins in the feedstock, the first stage of degradation, hydrolysis, produces large amounts of acids. The acids restrict the methane formation, which might be a reason for dividing the process in multiple phases. (Abbasi et al., 2012)

In addition to the digestion itself, there are various possible **pre-digestion** steps, in order to optimize the process even further. Pre-treatment might be needed since the feedstock composition may be varying, and especially viscous, fibrous and granular biomasses are difficult to move and mix. With correct pre-treatment, the degradation and gas yield may also be improved and the process stabilized. Even the pre-digestion storage may be viewed as a pre-treatment step: the correct (usually anaerobic) storage facilities prevent the formation of process-harming fungi, and preserve, or even increase, the methane production potential of the feedstock. (Mudhoo, 2012)

A simple crushing or chopping of the feedstock to reduce the particle size has been proven to increase the methane yield. The combination of heat and pressure is also used for breaking the structure of the feedstock, and with sufficient temperature and time, the thermal pre-treatment also works as a sanitation measurement. Chemical and biological pre-treatment methods and the combinations of mentioned methods have also shown increase in degradation rate and methane production. It needs to be noted, however, that pre-treatment increases costs via energy consumption and thus, pre-treatment is not always profitable. And if a pre-treatment method is used, it needs to be chosen considering the feedstock. Taking the entire production chain in account could be helpful: if there is excess heat produced in biogas utilization, for example, pre-treatment could be one place to utilize it. (Mudhoo, 2012)

2.1.2 Feedstock, products and utilization

Almost any kind of organic matter, with the exception of lignin, is suitable for AD. Originally, AD was used as a stabilization method for mainly animal manure and slurries and sewage sludge, as the treatment reduced both their volume and odours. After environmental awareness increased and technologies for utilizing different kinds of feedstock developed, the variety of used feedstock broadened. Nowadays, AD processes use various materials from organic municipal solid waste to industrial organic waste and crop parts from agriculture. (Wellinger et al., 2013).

During recent years, the growing and usage of energy crops as a biogas feedstock has also increased. Growing crops particularly for biogas production enables choosing the plants with the highest methane yield potential. However, the choice of using arable land for non-food production should be carefully considered. Crop rotation could offer a satisfactory solution for growing energy crops without reducing the amount of food production too much. But typically for biogas production, the decisions of crop utilization are case sensitive. (Wellinger et al., 2013)

In addition to the various feedstock options listed above, there is also interest and research examining aquatic biomass suitability for biogas production. The technology for utilizing seaweed and microalgae in biogas production is not yet mature – but it is good to acknowledge that waste and arable land amount do not necessarily limit the biogas feedstock amount in the future. (Wellinger et al., 2013) **Table 1** below presents some examples of typical feedstock and their qualities. In the table, Dry Matter (DM) content and Volatile Solids (VS) percentage of the feedstock are told, when available, as they affect the methane production potential.

***Table 1**. Characteristics of some biogas feedstock (Wellinger et al., 2013; modified)*

Type of feedstock	Dry matter (%)	Volatile solids (%)	Methane yield (m^3 CH_4/kg VS)	Methane production (m^3 CH_4/m^3)
Pig slurry	5	4	0.3	12.0
Intestinal content, cattle	12	9.6	0.4	38.4
Vegetable oil	95	85.5	0.8	684.0
Brewers spent grains	20	18	0.33	59.4
Typical energy crops	15-40	-	<0.45	-
Wastewater sludge	5	3.75	0.4	15
Food remains	10	-	0.5-0.6	-

As the table illustrates, there are considerable differences between different types of feedstock. Materials containing high content of sugar, starch, proteins or lipids are the most effective feedstock, as methane production is dependent on them. Materials with higher energy density of the mentioned macronutrients – sugar, starch, proteins or lipids (e.g. used vegetable oil) - could be profitable to co-digest as methane boosters, even though their volumes were not especially high. Materials with lower methane production potential, on the other hand, might have a lower, or even negative, price, which may make AD profitable. Other qualities of feedstock besides the dry matter content and methane yield affect its handling and the process as well. As mentioned in the previous chapter, the feedstock texture may require pre-treatment. Some feedstock may also cause significant odour emissions, which needs to be taken into consideration when planning transportation and storage. (Wellinger et al., 2013)

For biogas utilization, there are various different alternatives. The gas may be used as a fuel for boilers or in gas turbines for electricity or combined heat and power (CHP) production. Biogas can also be used as a vehicle or fuel cell fuel, or it can be injected into the gas grid. The different uses, the ability to substitute natural gas and the storage possibilities by liquidizing or pressurizing make biogas a versatile and flexible energy form. For any use, however, raw biogas needs to be cleaned, as the impurities may have harmful effects on the utilization process, emissions and human health. The level of the purification required depends on the planned use, and some refining methods are very expensive;

therefore, it is preferable to plan the entire biogas chain to the end-user at once, if possible. (Sun et al., 2015)

For gas purification, there are a variety of different methods with different efficiency and cost. The most typical methods utilize water; for example, pressure swing adsorption and water scrubbing, which is also the primary purification method in Finland. Absorption may also use other substances than water. In addition to these, there are membrane and cryogenic upgrading technologies, and combinations of these. The primary goal is CO_2 removal, as its volume is the highest of the unwanted components. Desulfurization is essential as well, as sulfuric acid may damage the equipment using the gas. But monitoring and lowering the level of one impurity is not enough, as the impurities also react with each other. Injection to the gas grid, and especially compressing or liquidizing the biogas requires highest levels of purity, whereas heat and power production do not require such high levels of purification. (Wellinger et al., 2013).

Digestate is the part that is left from the feedstock after AD, which means that the quality of the digestate is as varied as the quality of the initial feedstock. But typically, the produced digestate is rich in nutrients, which makes digestate an excellent fertilizer – or fertilizer raw-material. As mineral nitrogen and phosphorous are fossil materials with limited reserves and a fluctuating price, interest in nutrient recycling via digestate utilization is increasing. Because of the nutrient recycling, using the digestate as a fertilizer is considered to be the most sustainable use. However, applying digestate for crops dedicated for feed or food production creates quality requirements for the product. Both EU and national regulations set limits values for heavy metals, physical impurities and harmful pathogens. Removing the unwanted components from the digestate is not something that can be done subsequently. Producing fertilizer-quality digestate includes choosing the high-quality feedstock and correct pre-treatment steps, and requires control over the digestion process. (Wellinger et al., 2013) This is yet another aspect of the biogas process that highlights the importance of entire system optimization.

After quality control, a high-quality digestate may be applied as a fertilizer, in a similar manner like manure; but the digestate may also be processed further. Separating solid and liquid phase is the simplest way of processing, and for that, there are cheap technologies. Separation reduces the digestate volume, and may make transportation profitable for longer distances. There are various different separation techniques, but typical for all of them is to add flocculation agents to the digestate. The dry and solid fraction may be used as condensed fertilizers, or processed even further. Some sources consider further processing automatically unprofitable as it increases costs considerably. (Wellinger et al., 2013) There are, however, success stories of this as well. A Swiss biogas plant produces annually around 10 000 tons of high-quality, concentrated fertilizer from 61 000 tons of feedstock by solid-liquid-separation, ultrafiltration, pH balancing and reverse osmosis. Some of the increased costs can be covered as farmers are willing to pay a higher price from a higher-quality product. In this case, steady demand of the high-quality digestate enables the refinement. (IEA Bioenergy, 2016a) But if the refinement technologies develop and bring the prices down, digestate refinement, and even nutrient separation, could become profitable more often.

If the digestate quality or long distances make it unprofitable to utilize it as a fertilizer, there are also other alternatives: it may be used as a soil conditioner, or it can be used for energy production after dewatering. But regardless of the end-use of the digestate, it needs to be planned ahead, as wrong placement may cause eutrophication. (Wellinger et al., 2013) In conclusion, the various different possibilities for each production step illustrate the versatility – and complexity- of biogas production. As the quality of the feedstock affects the entire process from required pre-digestion to digestate usage, biogas production always forms a multi-variable equation. The versatility should not be viewed as a mere difficulty, as it also offers large resources for production. But it should be noted that the different technical options are not the only variables in the biogas equation. The different steps are usually operated by different actors, which means that the social aspects of the biogas network complicate the observation even further. To better understand the formation and functioning of these systems, industrial ecosystems are examined. But first, the biogas production and utilization effects on GHG emissions are observed.

2.1.3 Biogas and greenhouse gas emissions

The greenhouse gas reduction is one of the strongest motivators behind biogas production and utilization. For that reason, this chapter presents an example calculation of the possible effects the increase in biogas utilization could have on GHG emissions. The area used in the calculations was Pirkanmaa region, as two of the studied ecosystems are situated in the region as well. The results of the calculation may also be used as a motivation for promoting biogas activity in the target area. It should be noted, however, that the calculations presented below are purely based on waste amount and energy consumption and structure data, such as Pirkanmaa region population and emission factors. The calculations do not consider other elements that might affect emission formation; emissions from increased transport or life cycle assessment of new infrastructure, for example. The calculations are meant to give an estimation of the magnitude of the effect on GHG emissions, not exact numbers, as the emphasis of the thesis is on the ecosystem observation.

The calculations were executed by utilizing data about Pirkanmaa region population, typical amounts and properties of organic municipal solid waste (MSW) and municipal wastewater (MWW), data about the largest organic industrial waste producers and animal amounts and properties of their residues. (Mönkäre et al., 2016) From these, the theoretical biogas potential was calculated. In **Table 2**, estimated MWW and MSW fractions in Pirkanmaa area and their energy production potential through AD are presented. The original data is a calculation where the organic MSW and MWW from some Pirkanmaa municipalities were digested, (Mönkäre et al., 2016) and the entire Pirkanmaa numbers were extrapolated from these calculations based on population counts in each municipality (Tilastokeskus, 2015a). In **Table 3**, the energy production potential of animal manure and slurries through AD was estimated. **Table 4** collects the theoretical methane production and energy production potential of the feedstock fractions presented in **Tables 2** and **3.** In addition to these, **Table 4** includes the largest industrial feedstock flows (mainly slaughterhouses) and grass and garden trimmings from Pirkanmaa, and their qualities and theoretical energy potential (Mönkäre et al., 2016). Together, these give an estimate of the entire biogas production potential of the area.

Table 2. *The annual energy production potential of organic municipal solid waste (MSW) and municipal wastewater (MWW) sludge of Pirkanmaa region through anaerobic digestion (Mönkäre et al., 2016; Tilastokeskus, 2015a)*

Feed-stock	Orig. volume (t/a)	Calculated population (%)	Methane yield (Mm^3/a)	Energy potential (GWh/a)	Extrapolated potential (GWh/a)
Organic MSW	13 000	90.4	1.5	14.9	16.5
MWW sludge	122 738	72.3	2.4	23.6	32.6
Total					**49.1**

Table 3*. The annual energy production potential of Pirkanmaa region animal manure through anaerobic digestion (Hallvar, 2014; Mönkäre et al., 2016)*

Feed-stock	Animal number	Manure (m^3/a/animal)	Density (kg/m^3)	Total manure (kg/a)	Potential (kWh/kg)	Potential (GWh/a)
Cows	53 242	19.5	768.2	797 559 836	0.28	223.3
Pigs	86 161	2.4	640.8	132 508 725	0.34	45.1
Poultry	1 046 380	0.015	608.9	9 557 111.7	2.14	20.5
Sheep	10 548	1.5	556.3	8 801 778.6	0.76	6.7
Goats	994	1.5	556.3	829 443.3	0.76	0.6
Horses	2 026	12	506.5	12 314 028	0.76	9.4
Total						**305.5**

Table 4*. The annual combined energy production potential of every fraction produced in Pirkanmaa region through anaerobic digestion – previously calculated fractions, industrial organic waste and garden trimmings (Hallvar, 2014; Mönkäre et al., 2016; Tilastokeskus, 2015a)*

Feedstock	Volume (t/a)	Methane yield (Mm^3/a)	Potential (GWh/a)
Industrial organic waste	19 200	2.2	22.1
Garden trimmings and grass	7 000	0.8	8.0
Household organic MSW	14 380	1.7	16.5
MWW	88 500	3.3	32.6
Animal manure and slurries	96 1570	30.6	305.5
Total		38.6	**384.7**

After the combined potential of the fractions was calculated, the theoretical amount of biogas and its environmental effects was then compared to four different utilization possibility scenarios and their effect on current emissions. Biogas' GHG emission reduction potential is partly based on replacing other fuels with biogas, as their environmental effects are very different. For example, for gasoline and diesel used in vehicles, emission factor is 267g CO_2/kWh, and for combined heat and power production in Pirkanmaa, it is 220g CO_2/kWh. (Motiva, 2010) The emission factors for renewable energy sources are not this straightforward. Burning biogas causes emissions, and its calculated emission factor is almost as high as that of natural gas. But biomass is also binding CO_2 from the atmosphere while growing, and waste-derived feedstock is not only renewable, but also needs treatment. For these reasons, the emissions caused by biogas utilization are usually disregarded in the calculations (Tilastokeskus, 2016). Some sources use directly the emission factor 0 for biogas (Motiva, 2010) and that has also been used in the following calculation.

In **Table 5**, Pirkanmaa energy consumption is presented, as well as different effects of biogas on the GHG emissions while targeted on four different utilization scenarios. The calculated reduction in every scenario is the combined effect of every feedstock: MSW and MWW, manure and slurries and organic industry waste. The first two scenarios compare targeting the entire emission reduction on CHP production or traffic. The third scenario is a combination of these, calculated by targeting the traffic consumption amount on traffic, and the rest to CHP. The last scenario assumes that the entire emission reduction could be targeted towards traffic. Pirkanmaa energy consumption including housing and agriculture, industry, service sector and building are from Energiateollisuus (2016) statistics. Traffic energy consumption and emissions, on the other hand, are scaled from a calculation made for Lappeenranta region, estimating the amount of cars and car usage based on Pirkanmaa population and statistics (Kiviluoma-Leskelä, 2010; Tilastokeskus, 2013).

Table 5. *Total calculated CO_2 emission reduction potential from biogas utilization in Pirkanmaa region. Four different cases (CHP, Pirkanmaa traffic, combination of these and heavy traffic). Each row represents a calculation of biogas targeted on different use, and the emission reduction is then compared to present Pirkanmaa emissions. Calculations are done assuming current effectiveness of energy utilization methods. (Energiateollisuus, 2016; Kiviluoma-Leskelä, 2010; Motiva, 2010; Table 4; Tilastokeskus, 2013)*

	Emission factor (g CO_2/kWh)	**Consumption 2014 (GWh)**	**Present emissions (t CO_2/a)**	**CO_2 reduction (t CO_2/a)**	**CO_2 reduction (%)**
CHP	220	5 925	1303500	84634	**6.2**
Traffic	267	222	59274	59274	**4.3**
Combined	-	6147	1362774	95068	**6.9**
Heavy traffic	-	-	-	102714	**7.5**

The simplified calculation suggests that the reached emission reduction would be over 4% of Pirkanmaa region emissions with every utilization method. The controversy between the lowest emission reduction and the high emission factor of traffic can be explained by the fact that Pirkanmaa region is able to produce more biogas than the traffic in the area requires. That is why heavy traffic is included in the scenario; the most significant emission reductions (7.5%) could be reached by utilizing the entire produced gas amount in traffic by finding additional fuel markets outside Pirkanmaa region, e.g. from heavy traffic. Significant emission reductions could also be reached by guiding the entire gas amount to CHP production (6.2%) or utilizing as much on the local traffic as possible, and the rest in CHP production (6.9%).

However, the reality of biogas effects on GHG emissions is much more complex. The emission factors for fossil fuels may be reliable, but the factor for biogas only considers the utilization. This evaluation disregards the different purity requirements for different uses, which could create a difference in the results, as the energy consumption of purification methods differ considerably. What is more, the feedstock and end-product transportation may also create a difference in the total emission amount, and thus affect the overall emission/produced energy unit ratio. (Ravina & Genon, 2015) It is also highly unrealistic to assume that every feedstock fraction in its entirety could be utilized; there might be alternate uses for some fractions, or transportation distances could exclude some of the feedstock, for example. The calculation does, however, give a ballpark figure. And there are some potential fractions that are not included in the calculations – energy crop cultivation in scenery fields, for example – which could even add to the amount. Another factor that needs to be considered is that the calculations are done assuming current effectiveness of energy utilization methods. As these will develop in a more energy-effective direction, the emission reduction percentage will rise in every scenario.

Yet another noteworthy factor in the emission assessment is the methane slip. As methane is 25 times stronger greenhouse gas than CO_2, even small amounts of methane escaping the process can make a difference. Methane can escape during production, gas upgrading or transportation, and every step of the process is a risk. It has been calculated that even a few percentage units of methane slip can make a difference, determining whether the biogas process has a positive or a negative effect on GHG emissions. The gas upgrading step is risky, and thus requires careful planning. (Ravina & Genon, 2015) The GHG effect of methane is acknowledged in the gas industry, and research is ongoing to detect and eliminate possible leaks even more effectively. (IEA Bioenergy, 2016b)

2.2 Natural gas and gas infrastructure

Natural gas has many similarities with biogas, which means that the gas infrastructure originally created for natural gas may be utilized in biogas distribution as well. In the following chapter, natural gas qualities and Finnish gas infrastructure are viewed.

2.2.1 Natural gas qualities and utilization

Natural gas is a fossil fuel, formed over a long period of time from organic matter trapped within sediments, not unlike other fossil fuels. The so-called raw natural gas consists mainly of methane (CH_4), but includes also heavier hydrocarbons (e.g. ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10})) and other gases like nitrogen (N_2), carbon dioxide (CO_2) and hydrogen sulfide (H_2S). The consistency of natural gas depends on the source. Like biogas, natural gas is a versatile fuel, and has a high calorific value because of the high methane content. Natural gas utilization and infrastructure are observed, as biogas may use the same infrastructure with sufficient refinement. (Mokhatab & Poe, 2012)

As natural gas is lighter than air and has a large volume, its transportation from the source needs to be planned. With large gas reserves and reasonable distance to the end-user, gas pipeline is the most logical solution. The pipeline offers buffer for gas production and utilization and with that, operational reliability. However, energy markets are shifting towards more decentralized direction, which calls for flexibility and alternate transportation methods. With decentralized biogas production and other more flexible alternatives becoming more common and supporting the gas infrastructure, gas production and utilization is becoming more common outside the pipeline as well. The most common alternative for pipeline distribution is utilizing Liquefied natural gas (LNG) technology. Lowering the gas temperature to approximately -162°C liquefies natural gas, reducing its volume to 1/600 of the gas volume at normal conditions. This enables gas storage, if needed, or economical transportation for longer distances. However, the building costs of LNG plant are rather high, because of the typically distant locations, strict safety measures and large amount of cryogenic material needed, among other things. LNG also requires regasification facilities after the transport and before the end-user. (Mokhatab & Poe, 2012)

In circumstances where gas pipeline or LNG is not viable, Compressed natural gas (CNG) might be. The electricity needed for gas compression is approximately 40% of the amount of electricity required for liquefying. Depending on the purity of the compressed gas, the pressure is between 125 and 250 bar; the larger the methane content compared to other gases, the higher pressure and smaller volumes are reached. In any case, volumes of CNG will remain higher than those of LNG, which means that economic viability of CNG usually requires shorter distances than LNG. There are also other suggested solutions for natural gas storage and transportation, like gas-to-solid -technology. However, the observation in this thesis will be limited to pipeline, LNG and CNG solutions as they are the ones that have reached technological maturity. (Mokhatab & Poe, 2012) In conclusion, the choices are case sensitive, very much like in biogas processes, depending on the gas source, end-users and distances.

As a fuel, natural gas is as versatile as biogas. The following chapter presents current natural gas use an infrastructure in Finland.

2.2.1 Gas infrastructure in Finland

As the case areas of this thesis are located in Finland, a quick observation of gas infrastructure and utilization in Finland is needed. In Finland, the most common gas distribution method is the pipeline. Originally, the pipeline was built for natural gas distribution, and still, a major part of the gas in the grid is natural gas imported from Russia. In 2014, for example, 2930 million m^3, or equivalent to 29,3 TWh, natural gas was imported and distributed via gas grid (Energiavirasto, 2015). In the same year, the amount of utilized biogas was 130 million m^3 or 613,3 GWh (Huttunen & Kuittinen, 2015) – 4,2% of the total gas amount – and part of it was distributed via gas grid. In addition to the main network, there are also 13 small, local networks (Mutikainen et al., 2016). In **Figure 1**, the primary Finnish gas network is presented.

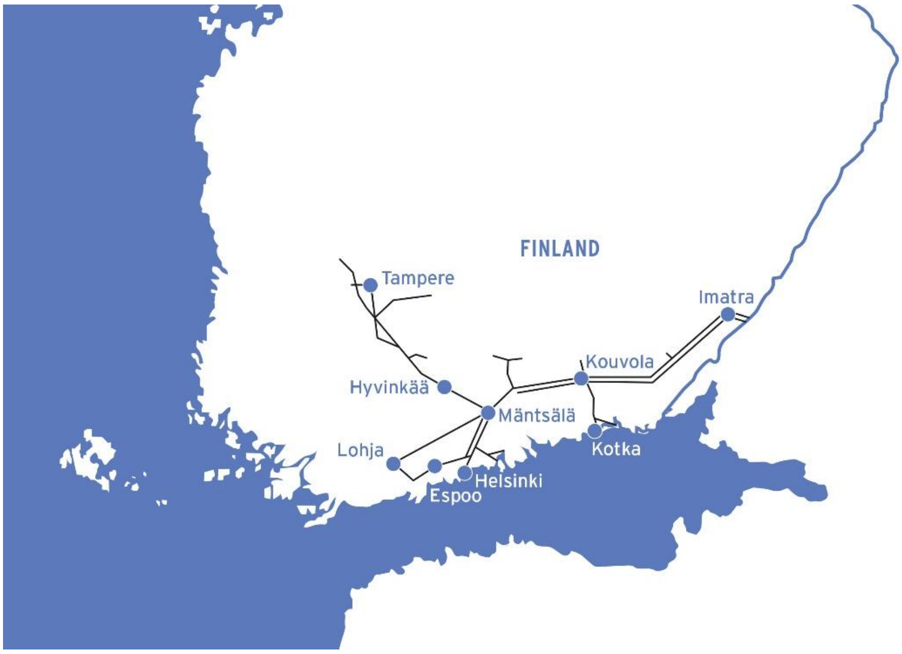

***Figure 1**: Gas network in Finland. (Gasum Oy, 2016; modified)*

In addition to the original use, the gas grid is utilizable for biogas distribution as well. The raw biogas needs to be purified, but after that, the fuels are practically identical. In 2014, 34 GWh equivalent of biogas was injected in the gas grid from three larger biogas production units in Lahti, Espoo and Kouvola. (Gasum Vuosikertomus, 2014) Compared to natural gas, the amount of biogas in the grid is still relatively small, but the potential is interesting. It has been estimated that with the biomass potential in Finland, over 30% of the annual utilized natural gas amount could be replaced with biogas. (Gasum, 2016b) As the gas grid offers buffer between production and utilization, close proximity to the grid might lower the threshold for biogas production initiation. Biogas grid injection requires purification, to get the methane levels as high as 98%, and constant monitoring of injected gas quality. The purity level required for grid injection is lower than for liquidation or pressurizing biogas, and rather easily profitable. (Wellinger et al., 2013) In the light of the limited reserves of natural gas and this information, it is thus probable that the share of biogas in the gas grid is going to rise in the near future.

Finnish gas consumption is concentrated on combined heat and power (CHP) production. About 8% of Finnish primary energy and 22% of district heat is produced from natural gas and biogas. Another important use is industry, where gas is utilized as a raw material, in addition to the heat and energy production. Smaller, but growing, areas of gas utilization are direct household utilization via gas grid (about 30 000 households) and using gas as a vehicle fuel. Both of these uses have concentrated on southern Finland, where the gas grid is located, but expansion is possible. (Gasum, 2016c) In addition to the gas pipeline and separate biogas production units, a larger LNG terminal is going to be completed 2016 in Pori. In the area, there will be a 12 km pipeline for local gas distribution, but in addition to this, LNG may be transported by sea or by tank trucks. The terminal may distribute liquidized biogas as well as natural gas, as long as the purity of the gas is sufficient. (Gasum, 2016d) The gas fueling stations in Finland are presented in **Figure 2**:

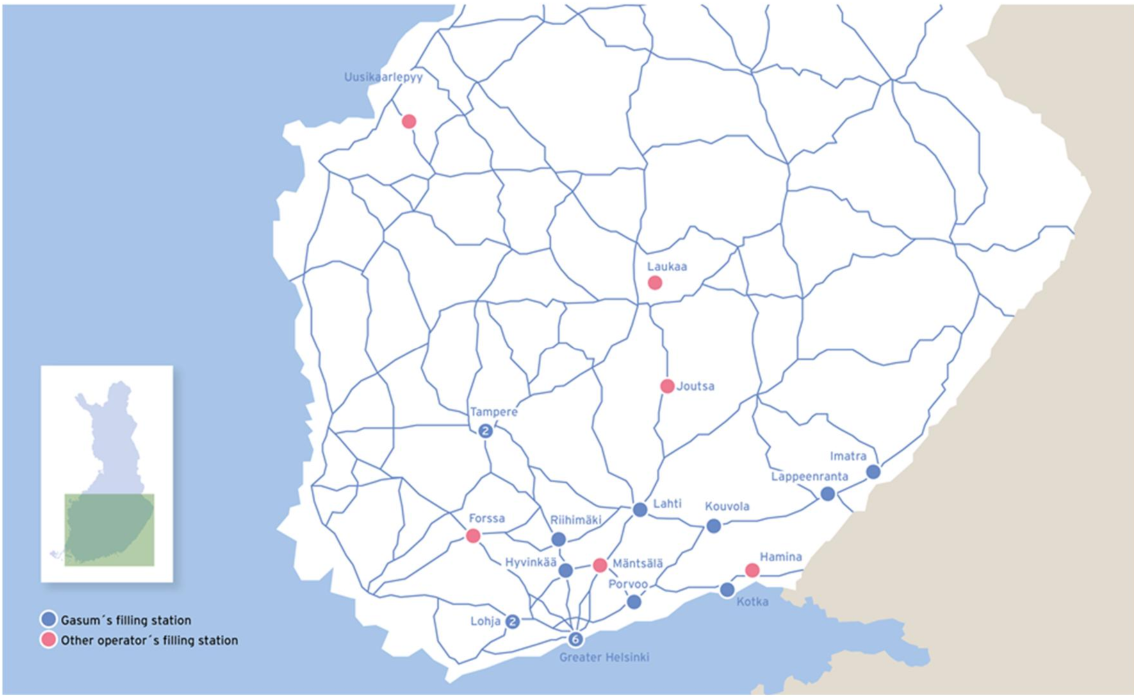

***Figure 2**: Gas-fueling station locations in Finland (Gasum kuvapankki, 2016)*

The majority of the stations are Gasum's refueling stations, located by the pipeline, distributing the gas from the gas grid. The stations in Hamina, Mäntsälä, Forssa, Joutsa, Laukaa and Uusikaarlepyy owned by other actors, for example private entrepreneurs selling self-produced, purified biogas. In Greater Helsinki, there are 6 stations, and in Lohja and Tampere, 2 in both. Other marks represent one station. (Gasum kuvapankki, 2016) The amount of gas vehicles in Finland is rather low, 1813 in 2015 (1542 in 2014), which represents 0.06 % of the total fleet of 3 031 450 cars. (Trafi, 2015) The gas cars are mostly located in the southern Finland, where the fueling stations are situated, which is natural;

the current fueling station grid encourages investing in a gas car in southern Finland, but not so much in the north. On the other hand, the smaller demand for fueling stations in the north makes it challenging to invest in new stations there. This is a classic example of the so-called chicken-and-egg dilemma of which should come first to a new area, the supply or the demand, as either one cannot exist without the other. The sparse population density in Finland, and its concentration in southern part of the country (Tilastokeskus, 2015b) may also have slowed down the fueling station grid expansion.

The will and pressure for increasing the amount of fueling stations does, however, exist. According to the EU-directive for clean vehicle fuel infrastructure, gas refilling stations should be located at 150 km distances at most by year 2020 (2014/94/EU), which means further expansion outside the pipeline. Gasum has a plan for 35 new fueling stations, also outside the grid, by 2025 (Gasum, 2015). This would be a substantial growth, compared to the current 24 stations. But as other development rate is rather modest (Huttunen & Kuittinen, 2015), reaching the EU-directive levels still seems somewhat challenging. Some legislative measures may be expected to make biogas production, purification and distribution more appealing, to reach the set goal.

2.3 Sustainability transitions and biogas

Biogas is an important part towards a more sustainable future, but as Chapter 2.1 introduced, it is not a very straightforward energy source. In order to reach synergies, optimal performance and economical profitability, biogas production and utilization have a tendency of forming unique, multi-field ecosystems around them. In the hopes of better understanding these ecosystems and the necessary transition process, the following chapters introduce some relevant theories. Biogas ecosystems are observed via industrial ecosystem development theory and socio-technical transition (ST-transition) theory, utilizing also some examples of successful biogas ecosystems. The goal is to better understand drivers and hinderers behind biogas ecosystem formation.

2.3.1 Socio-technical transitions

The concept of socio-technical transitions was chosen for biogas ecosystem observation because of its comprehensiveness. The theory also bounds biogas development to wider socio-technical transition towards sustainability. As the term indicates, in addition to the technological side of transitions, the theory also considers a multitude of other factors, e.g. user practices, regulations, industrial networks and infrastructure. (Geels, 2002) First, the different terms used in socio-technical transition theory are introduced. After that, the interactions between the three levels are discussed.

Nelson and Winter (1982) originally introduced the concept of *technological regimes*, which refers to regularities and patterns in thinking. When similar patterns appear in industrial and scientific surroundings alike, and a technology becomes a norm, it is called a technological regime. This term was later expanded by Geels (2002) to **Socio-technical regimes** (ST-regimes), in order to include the social and behavioral elements of regimes that also influence their development. More precisely, Geels (2002) identified seven different dimensions from the regime: technology, user practices and markets, symbolic meaning of technology, infrastructure, industry structure, policy and techno-scientific knowledge.

Socio-technical regimes are situated in **Socio-technical landscape**. The term refers to a set of technology-external factors, which set frames for technological development, such as environmental challenges, cultural and normative values, political coalitions (such as E.U.), migration, wars and economic growth. (Geels, 2002) New **technological niches** can be seen developing outside the dominant regimes, but nonetheless, prevailing regimes and landscapes strongly affect their success of failure. The structure and changes of ST-transitions are portrayed in **Figure 3**.

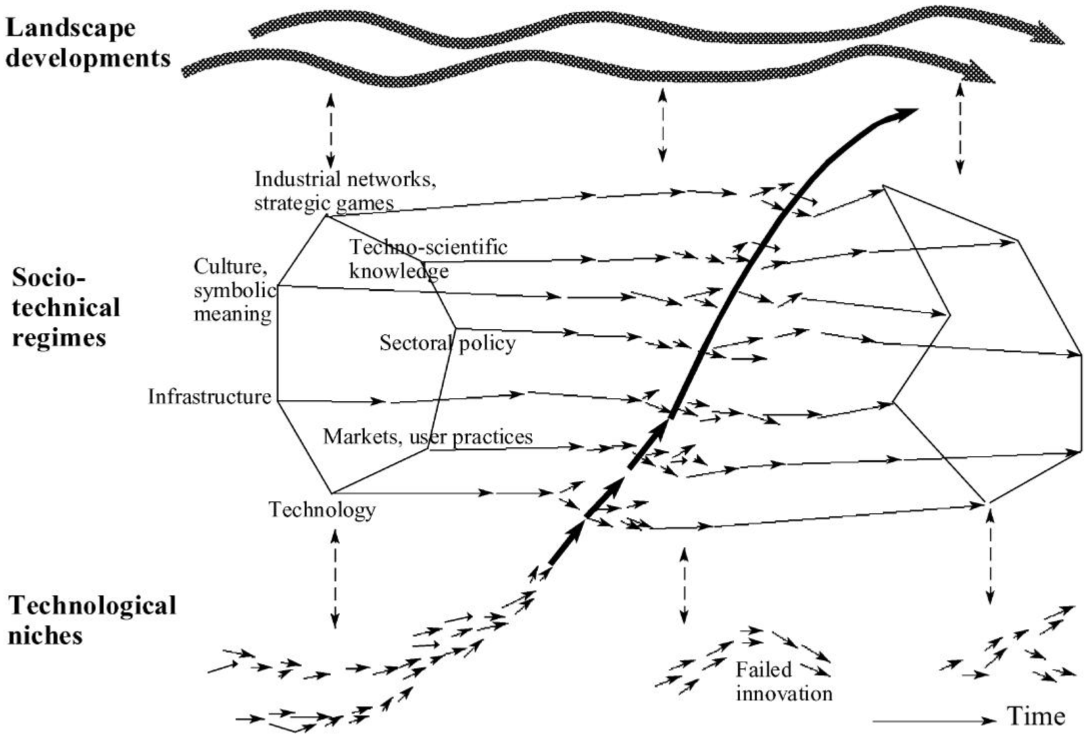

Figure 3*: Socio-technical transition process in socio-technical structures (Geels, 2002)*

As **Figure 3** illustrates, there are various different connections and interactions between, and inside, ST-regimes and landscapes that affect the niche development. The different aspects of ST-regime are illustrated with long, parallel arrows, representing stability; usually the different dimensions co-evolve in harmony, and innovations evolving in the regime are of incremental nature. But the internal dynamics between the dimensions may also result in frictions, and these instances are represented with smaller, divergent arrows.

The frictions may be a consequence of changes in one or more dimensions, if other dimensions have a difficulty to adapt. It needs to be noted that shifts in the landscape may also create pressure for a change in the regime, which may then cause friction among the dimensions. (Geels, 2002)

Either way, the frictions in the regime create an opportunity for radically new innovations to break through and become a dominant technology in an otherwise stable regime. This phenomenon is shown in the picture as longer, thicker arrows arising from the niche-level, with a convenient timing considering the frictions in the regime. Other than that, niche technologies are illustrated with short, divergent arrows, as the dominant design is yet to be established. These arrows also suggest that a new technology is more likely to become mainstream if it is result of *niche-cumulation*; in other words, innovations inspiring further innovations, and supporting and improving the previous ones. (Geels, 2002)

Waiting for the suitable circumstances for a niche to break through is not the only possibility. Better circumstances can be deliberately created to protect niches in the challenging early stages. Creating such temporary “protective space” against the selection pressures of an existing regime is considered useful, even crucial, and this can be done by shielding, nurturing and empowering the innovations. The terms are quite describing; *shielding* refers to creating more favorable circumstances for the niche, utilizing investment subsidies of feed-in tariffs, to mention a couple examples. As the regimes are multi-dimensional, shielding is also the most beneficial if it is targeted towards various different aspects of the regime, instead of just one. *Nurturing* means supporting the development in the protective space that shielding has created, by assisting learning processes, helping networking processes and articulating expectations, for example. The goal of the process is that with time, the shielding structures become redundant, as the niche reaches such a level of maturity that it is competitive in the existing regime. This is called empowerment via *“fitting and conforming”*. However, it is also possible that the transformation happens in the regime instead of the niche; this is called “*stretching and transforming”*. (Smith & Raven, 2012)

It is typical, but not mandatory, that a so-called “system builder” is a driving force behind a socio-technical transition. The system builder may be an organization or an individual connecting different actors and pushing the process forward. While a system builder is not always part of a development process, a presence of one certainly accelerates the process. (Fallde & Eklund, 2015)

The relations of these terms in biogas context are not established. In this thesis, biogas ecosystems and biogas-related technological innovations are referred to as niche innovations. Legislative measures to promote biogas are considered shielding measures and protective space. In the next chapter, the principles of industrial ecology and industrial ecosystems are introduced, as they are essential in understanding biogas ecosystems.

2.3.2 Industrial ecology and industrial ecosystems

The concept **of industrial ecology** (IE) is a comprehensive framework for guiding the industrial systems towards a more sustainable basis. The concept of industrial ecology was developed as a reaction to the realization that industrial world is not separate from the natural world, but instead, it is strongly dependent of natural constraints. This fact actualized with the awareness that certain natural resources are going to last mere decades with current use. The main principles of IE can be summarized to four points (Lowe & Evans, 1995):

- The industrial operators must function within the limitations of their surroundings and the biosphere
- Natural ecosystem model offers a powerful tool to guide industrial designing and management
- Economic benefits and competitive advantage may be reached by high material and energy efficiencies in resource utilization and recycling
- Without the long-term goal of global viability and preservation of environment, short-term success is meaningless.

For the purpose for realizing IE ideology goals, the concept of **industrial ecosystem** was presented. Industrial ecosystem refers to integrated, usually multi-field system consisting of actors (e.g. companies), material and energy flows and information flows that connect the actors with each other and with their surroundings. (Korhonen & Snäkin, 2005; Lowe & Evans, 1995) The typically multi-field biogas ecosystems fall to this category quite naturally. The motivation behind IE ideology and industrial ecosystem research might have been slightly different than the driving forces behind biogas ecosystems. Typically, more traditional industries make profit without forming ecosystems, but seek ecosystem formation for numerous reasons: profits via greener image, or more efficient recycling because of risen waste disposal costs, for example. (Lowe & Evans, 1995) Biogas systems, on the other hand, typically require the ecosystem formation in order to reach economical profitability. (Olsson & Fallde, 2015) The formation, functioning and benefits of ecosystems still remain the same, regardless of the reasons for formation. The different drivers and motivation should be acknowledged, however, as they can be utilized when planning to form novel collaborations.

In addition to observing biogas ecosystems via industrial ecosystem concept, it needs to be recognized that the systems work and interact within an even larger entirety. To help this observation, the concept of **socio-technical transitions** (ST-transitions) and its components were previously introduced. By combining these two theories, we proceed to the key questions of this thesis; *why* and *how* do biogas ecosystems form and function? Can their formation be increased or encouraged, and if so, by what methods? These questions are discussed in the following chapter with the help of presented theories and some examples of biogas ecosystems.

2.3.3 Biogas ecosystems

As mentioned before, biogas production and utilization tends to form a broader ecosystem, and **Figure 4** presents some of the most typical components of such a system.

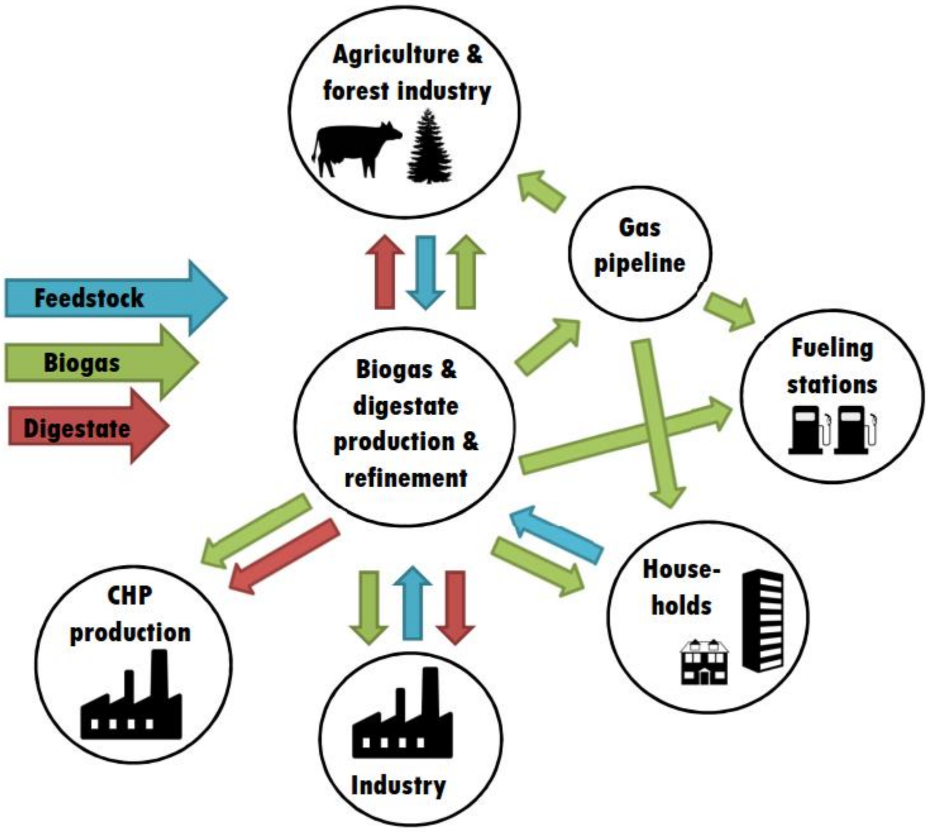

***Figure 4**: An overview of biogas ecosystem and possible actors and material flows.*

It needs to be noted that the possibilities represented in the **Figure 4** do not all actualize in a single ecosystem, but the suitable combination of actors and structures will be composed according to the circumstances. The amount and quality of feedstock available economically is usually the first factor that determines the size of the production unit. Very small-scale producers, for example family farmers, may not even need to sell the products if they can be utilized on-site. For a moderate-scale production, it might be optimal to choose only one, most profitable utilization method, as gas processing for different uses requires resources. But for a larger production unit, it might be beneficial to find more than one use for the gas. The best utilization options mostly depend on the structure and location of gas demand. But other factors, such as the surrounding infrastructure, may affect the situation as well. And in addition to the gas demand, digestate demand and quality requirements need to be considered as well. Agricultural ecosystems have the possibility to utilize the digestate as a fertilizer in the same farms that delivered the manure used as a feedstock. This usually means short transportation distances; and reduces the prejudice towards the biofertilizer, as the farmers know its origin. (Sitra, 2016; Tsvetkova et al., 2015)

Biogas technology and biogas ecosystem locations in ST-landscape must be determined. Among success stories, there have also been recent failures in biogas production (Cavicchi, 2016; Olsson & Fallde, 2015). The rather recent overview of biogas technologies suggests that future development is needed in practically every aspect of biogas process. (Wellinger et al., 2013) Rather noteworthy is also the fact that while planning new biogas production units, the economical goal is often a break-even –situation, not profit. (IEA Bioenergy, 2016a) From these matters, it can be argued that technology is not yet mature, but instead, the biogas ecosystems represent technological niches. And for them to become a part of ST-regime, substantial development is needed.

As the ST-transition model proposes, different factors may affect a niche technology rising to be part of an existing regime. The first one, internal conflicts within the current regime may create openings for alternate solutions. But in the case of biogas, the current regime consists of current heat and energy production and utilization systems, waste management, fossil fertilizers and vehicle usage. These structures are highly stable because of the heavy infrastructure, and also because they perform key societal functions, and it is difficult to imagine internal conflict of such a magnitude that it would initiate radical change. The shrinking amounts of fossil resources have been acknowledged for a long period of time, but even though this has increased interest in biogas, global biogas production rates still remain rather modest. This suggests that if biogas production is to be increased, the protective space should be created deliberately, by shielding and nurturing.

Such measures have already been taken in Finland. In 1997, collecting methane emissions from larger landfill sites became mandatory (861/1997). The vehicle tax reform in 2004 lowered the taxation of gas-fueled cars to a more reasonable level, making investing in them more interesting (1281/2003). From 2011, with certain terms, new biogas production units have been able to receive feed-in tariff for the heat and electricity injected in the grid (1260/1996). Alternately, biogas production units may apply for investment support meant for renewable energy production (Motiva, 2016). In 2011, a separate investment support for agricultural biogas production was created as well, for individual farmers and collaborations of farmers (354/2011). The will to promote biogas with legislative measures is clear, and at the end of 2015, Finnish Ministry of Employment and Economy created a working group to assess which measures for promoting renewable energy would be the most effective (Kymäläinen & Pakarinen, 2015). But let us take a closer look at the effects of these measures on the actual biogas production and utilization. **Figure 5** illustrates the development of production and utilization of biogas in Finland during the last 20 years.

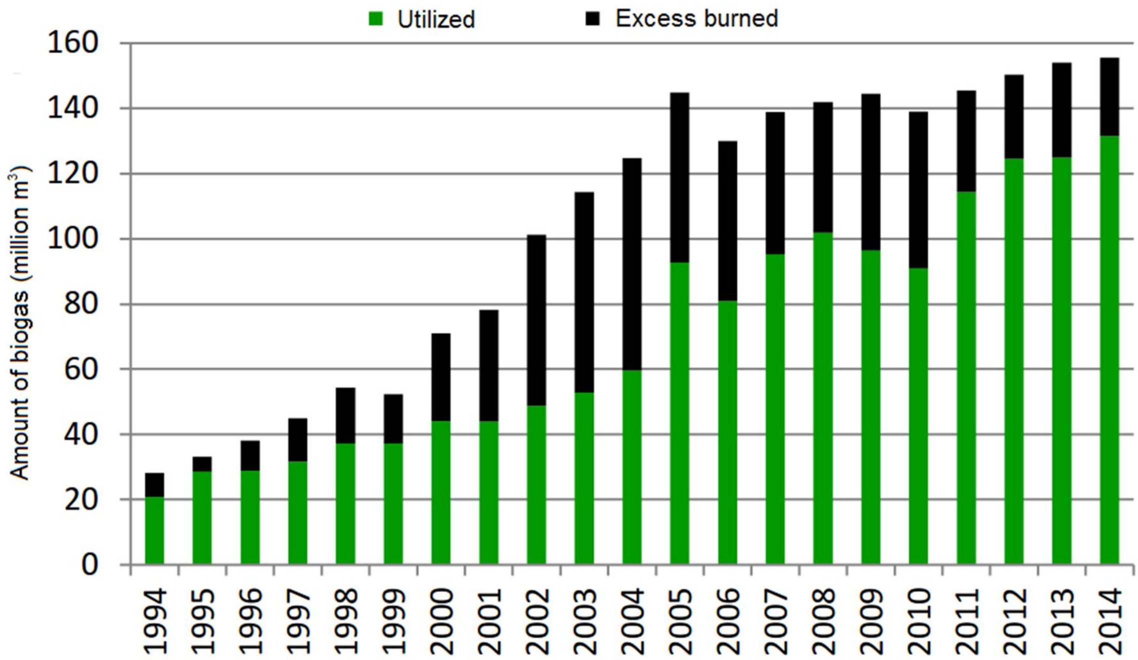

Figure 5*: Biogas production and utilization in Finland 1994-2014 (Huttunen & Kuittinen, 2015; translated)*

The effects of the landfill gas legislation can be clearly seen from **Figure 5**, as the amount of biogas collected or produced annually in Finland over tripled in a decade from 1997. However, during the last 5 years, the Finnish biogas production has settled to an almost constant level. This indicates that even though the law had a desired effect, it did not stimulate considerable biogas production outside the landfill sites. Landfill sites as gas source are also beginning to diminish, as legislation is prohibiting organic waste placement in landfill sites from 2016. (Mutikainen et al., 2016) The agriculture-targeted investment support seems to have a positive response: in 2014, 9 new environmental permits were granted for individual farmers, which is a significant increase to the 12 units that were operational in 2014. The produced biogas volumes of these units are, however, rather small. (Huttunen & Kuittinen, 2015) From other investment supports and feed-in tariffs, there can be seen a more prominent effect; larger biogas production units have begun operating in 2015 in Ämmässuo, Virrat, Kuopio and Honkajoki. Combined, these facilities produce a 114 GWh annual amount of biogas in energy units, which is an almost 20% increase to the 2014 gas production level. (Mutikainen et al., 2016) This production is so new that it is not yet visible in **Figure 5**.

In summary, even though the final results will be seen in the future, these shielding measures seem to have had a very positive effect on biogas production and utilization. The relative increase in the production and utilization in two decades seems impressive. However, the truth is that Finland is still quite far from reaching the goals set for biogas production. In 2003, a working group of the Finnish Ministry of Trade and Industry created an action plan proposal for increasing the production and usage of renewable energy

(KTM 5/2003). For 2025, the targeted amount of utilized biogas energy was 2.22 TWh and for 2010, there was an intermediate goal of 1.17 TWh. As we now know, the actual utilization in 2010 (0.42 TWh) fell rather far from the set target, and it seems very unlikely that the goal of 2025 would be reached with current methods either. (Huttunen & Kuittinen, 2011; KTM 5/2003) The set goals are, however, completely reachable: the annual economically profitable biogas production potential in Finland has been calculated to be as high as 9.2 TWh. In 2014, 6.7% of this potential was realized. (Huttunen & Kuittinen, 2015; Tähti & Rintala, 2010) Tähti and Rintala (2010) have estimated the complete theoretical biomass potential to be as high as 24.4 TWh, and the 9.2 TWh to be the economically and technologically profitable part. The 38% profitability seems like a modest estimate. In addition, as biogas technologies are constantly developing, the profitable part might well become larger in the near future. But it needs to be noted that Finland is not lagging behind in biogas promotion alone; even Germany, which is considered an example and a forerunner in biogas production, currently utilizes only 10 % of its feedstock potential in AD (Olsson & Fallde, 2015).

The effect of incentives on AD has also been researched by Edwards et al. (2015). Five countries (Denmark, Germany, Great Britain, Australia and USA) with different types of incentive structures and different amount of existing AD production were studied, and correlations between different incentives and production were calculated. Similarly to the situation in Finland, the results were inconclusive. Some correlations were found, but they were not consistent in every researched country. Some larger increases in production could not be linked to any legislative measure to increase biogas production. But typical to all of these five countries was that the incentives were targeted towards production: feed-in –tariffs, investment supports and landfill levies for organic municipal solid waste (MSW) were used. The challenges found were also similar to Finland (Sitra, 2016): for smaller producers, it was difficult or even unprofitable to sell the excess heat or electricity. USA faced even more challenges with promoting AD, as the states are autonomous. If a state significantly increased landfill levies for organic MSW, for example, the reaction could be exporting the waste to neighboring state, instead of practicing AD on-site – especially if ready models for AD did not exist. (Edwards et al., 2015)

A noteworthy observation from Edwards et al. (2015) was also that as biogas production and utilization are promoted in the hopes of GHG reductions, other renewable energy forms are promoted as well. If the incentives for different renewable energy forms are very similar and a producer is undecided between options, biogas might not seem like the most appealing choice. The complexity of biogas production and requirement to monitor several different material streams might steer the choice towards wind or solar power. However, biogas has an advantage over these renewable energy forms as it is much easier to store. It should therefore be considered if the incentives for every renewable energy form should be equal – or if biogas should be prioritized over some other renewables. To give some perspective to the current situation, 0.2 million euros of AD-based feed-in tariffs was paid during the first three years of the tariff existing in Finland. During the same time period, Finnish wind power received 56.5 million euros in feed-in tariffs. (Kymäläinen & Pakarinen, 2015) Increasing all renewables is obviously a positive thing, and ideally, renewable energy production forms co-exist and support each other. But especially with smaller producers, investing can well be either-or- kind of decision.

Olsson & Fallde (2015) also propose that biogas production should be promoted from above by policies and laws, but it should be done with a different angle. According to Olsson and Fallde (2015), one reason behind the slowly increasing biogas production is the tendency of treating biogas as a homogenous, nation-wide system. In reality, biogas forms smaller, local, unique systems, which should be recognized in both research and policy-making, if their case is to be promoted. The same opinion arose in a workshop (Sitra, 2016), where a large representation of different Finnish biogas actors gathered to discuss the current situation and future prospects of biogas. A common consensus was that even though certain laws aimed to promote biogas production and utilization, legislation also created numerous obstacles, especially for smaller actors. For example, small-scale heat and electricity transfer is extremely difficult because of bureaucracy. Gas transfer is easier, but the necessary infrastructure for gas transfer does not typically reach the smaller actors. (Sitra, 2016)

When aiming to define circumstances when new technologies may rise from niche-level to be part of the regime, niche-cumulation was also mentioned. Niche-cumulation alone is not enough, as suitable circumstances are also needed, but it speeds up the process. With biogas, the research is ongoing, but Olsson & Fallde (2015) suggest that also for niche-cumulation, the research should be focused differently. Research has concentrated on technical and ecological aspects of biogas production and utilization, and only very recently, considered also the social aspect of networks. But again, this does not exactly simplify the situation. Studies suggest that because of their complexity, industrial ecosystems are extremely difficult to plan or create intentionally (Lowe & Evans, 1995; Olsson & Fallde, 2015). This is unfortunate in the light of biogas ecosystem observation, as there are no ready recipes for creating or replicating industrial ecosystems. Korhonen & Snäkin (2005) suggest that systematically analyzing successful industrial ecosystems and finding patterns and similarities could be useful, and this information could be utilized when planning new ecosystems. However, at the same time, it needs to be noted that direct replication is not possible (Tsvetkova et al., 2015), and the learned information always needs to be applied to the case-specific circumstances. Keeping that in mind, the next paragraphs observe successful biogas ecosystems, trying to find success factors, and also, causes for failure.

Finnish biogas ecosystems have not yet been researched in this manner. However, in Sweden, where biogas economy is more developed, Benjaminsson et al. (2013) have analyzed the functioning of 8 different agricultural biogas production systems in order to find factors of success and risks to be avoided. The report does not address the formation of ecosystems, only their functioning. The social aspects of ecosystems are not considered either, but instead, the report concentrates on the economical point of view. However, remembering other aspects of biogas ecosystems, the observation may be useful. The size of the observed production units varied between 2,6 and 40 GWh/a, most representing a size that is not typical in Finnish biogas production (Huttunen & Kuittinen, 2015). However, if the ecosystem formation becomes more common, the systems of this volume could generalize as well.

From the eight examined ecosystems, Benjaminsson et al. (2013) observed the feedstock distribution, size, ownership and gas demand, and collected the most successful policies. For the feedstock, **co-digestion** was seen as the most beneficial. Utilizing manure guaranteed steady feedstock flow, and cow manure also stabilizes the digestion process. In addition to this, (preferably long-term) partnership with food industry made the process more effective. For the ownership, **collaboration** and **co-ownership** of energy companies and farmers, for example, was seen as a good way to risk-minimization. For the size, there was no conclusive result; smaller units had relatively larger investment costs, but on the other hand, smaller units benefited from smaller feedstock costs as the transport distances were smaller. A long-term contract with a larger buyer or location near the gas pipeline obviously ensured a constant demand for the produced gas. It was noted that beginning production without a consumer base is always more demanding and should be planned carefully. In Gotland, for example, the gas production was not profitable at the time the report was published, as the agreed gas-fueled buses had not begun operating as planned.

The feed-in tariffs for renewable energy accelerated biogas production in Italy as well. The increase in production was not, however, without problems. Cavicchi (2016) researched biogas promotion in Emilia Romagna region, and reported reasons behind the difficulties. Cavicchi’s (2016) findings based on interviews and document analysis are in line with the previous research. The strict limits for investment support and tax exemptions led to rapidly-rising renting prices for the fields. The produced gas was used for CHP production, but as there was little need for heating, most of the produced heat was dispersed in the air, which lowered the income from the process. The less than optimal utilization choices were guided by the feed-in tariffs, which did not include other choices, for example vehicle fuel production. The exponential increase in biogas production also increased traffic in the area, and the escaped leachate caused odour and GHG emissions. The worse air quality and lower-than-estimated profits were very visible negative features of the process, which led to social conflicts; e.g. friction between small and big farm-owners, and resistance from the local inhabitants. Thus, the problems also became social. (Cavicchi, 2016)

Afterwards, it can be said that the initial problems from the Emilia Romagna region were caused by two factors: targeting the shielding measures on a very narrow area, and not considering the entire ecosystem at the planning phase, which led to controversies. The initial reasons (e.g. strictly limited feed-in tariffs and investment supports) may be fixed, and some measures have already been taken to this direction. However, this does not yet mend the situation, as the negative image of biogas production is much harder to remove than the reasons behind it. Even after the terms change, the prejudices remain, which is only natural – and a good reminder of the importance of both planning ahead, and considering the social aspects of the ecosystem. (Cavicchi, 2016)

A common nominator for some biogas success stories is a strong **system builder** that has driven the process forward. A system builder may be an organization, or even an individual with a position and drive to take the process forward. The bioenergy village of Jühnde in German had a mayor, who was an important promoter for the project, and succeeded in getting 70% of the villagers to join the project cooperative. In the case of Jühnde, the well-functioning social network was also considered essential, as the cooperative coordinated and led the entire project. (IEA Bioenergy, 2016a) Also in Kalmari family farm in Laukaa, Finland, the entire biogas project was based on an individual farmer's vision and expertise. The 50 local drivers utilizing biogas for their vehicles enabled the further expansion of the production. (IEA Bioenergy, 2016a) In the case of Linköping in Sweden, the municipality-owned company Tekniska Verken AB (TVAB) acted as a system builder, as an unusually large amount of biogas-related responsibilities – energy, sewage treatment and waste management - were concentrated on this one company. This, combined with the will to reduce emissions, drove TVAB to promote biogas and search for other potential actors. And this, in time, resulted in a biogas-fueled bus fleet of over 60 vehicles, and further spin-offs inspired by increased biogas production. (Fallde & Eklund, 2015) Of course, the various responsibilities concentrated on one company made it easier to notice these possibilities. With a more complex initial setting, noticing the biogas potential would have been more challenging – and combining even more actors may have required more time, and an even stronger system builder.

3 RESEARCH METHODOLOGY AND MATERIALS

In the following chapter, the studied cases, materials and research methods of the thesis are introduced. This thesis focuses on Pirkanmaa and Häme regions in central Finland. Currently, there is no significant biogas activity in the area, but there are several different actors interested in biogas. The gas pipeline also reaches the regions, which enables observing whether the existing core (the pipeline in this case) affects the formation of smaller biogas systems, and if so, how. The assumption is that the core can function without the smaller ecosystems.

3.1 Studied cases

The case ecosystems were chosen based on two factors; initial interest (and possible concrete plans) for biogas activity, and versatility between the systems. The pipeline and the case ecosystems are displayed on a map in **Figure 6**.

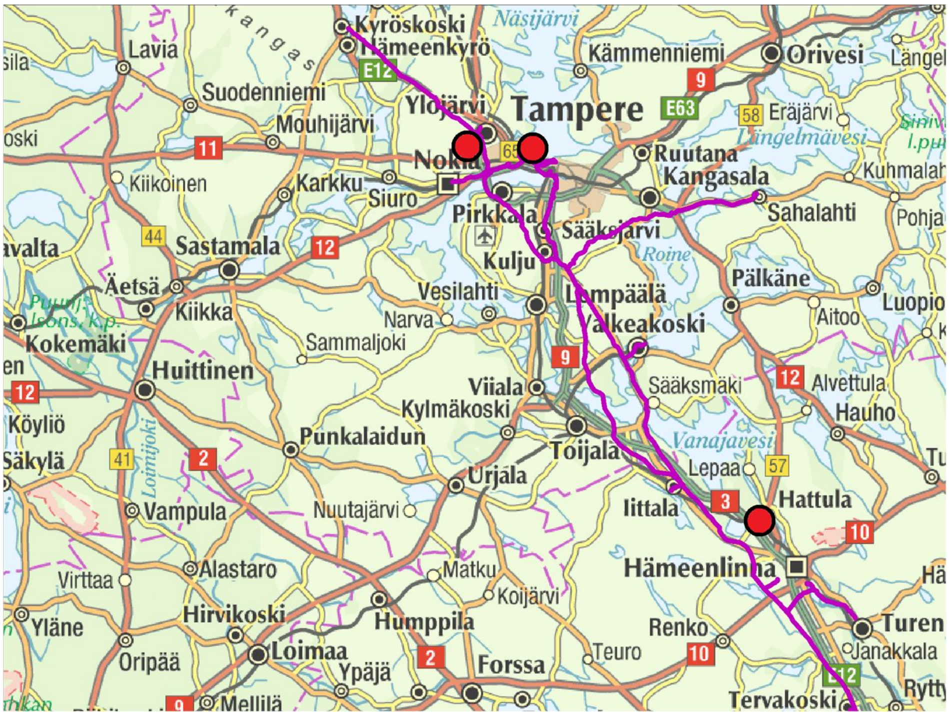

__Figure 6__. Case ecosystem locations and the gas pipeline. The case locations are displayed with red markers and the pipeline with purple. (Maanmittauslaitos, 2016; modified)

Case locations are displayed on a map with markers. Hiedanranta is located in Tampere, by lake Näsijärvi, and on its west side, there is Kolmenkulma location in junction of Tampere, Nokia and Ylöjärvi. Hattula is situated to the southeast of these cases, and all the cases are located near the purple pipeline (**Figure 6**). The represented actors attending each group interview are listed in **Table 6**.

Table 6. *Research setup – attended interviewees of each case.*

Case	Interviewee / representation
Hiedanranta	- City of Tampere - EcoFellows Ltd. - Tampere University of Technology - Centre for Economic Development, Transport and Environment (ELY-Center)
Kolmenkulma	- Regional waste treatment company - Premise development consultant company (2 participants) - The Central Union of Agricultural Producers and Forest Owners (MTK) - Centre for Economic Development, Transport and Environment
Hattula	- Hattula Municipality (3 participants) - Regional Council of Häme

As illustrated in IE theory, the role of a biogas ecosystem actor can be varying; from feedstock supplier to plant supplier, and from regional representation to gas or digestate refiner or end-user. All the studied ecosystems were in a planning or development stage, which shows in the relatively small representation of end-users in the interviews (Table 6). In the following chapters, each case setting is described in more detail.

3.1.1 Case urban vanguard ecosystem - Hiedanranta

The urban ecosystem case is an old industrial area, Hiedanranta, located approximately four kilometers from the center of City of Tampere, by the lake Näsijärvi. The zoning plan for the area rehabilitation is targeted to be ready in 2017, and first city plans that enable building are estimated to be completed in 2018-2019. The city wishes novel and environmentally-friendly solutions for the area, and the planning phase is a chance to affect. Without ready infrastructure, alternate solutions like low-water or waterless sanitation could be considered. One suggestion would be a smaller-scale biogas production nearby, using sanitation waste and organic MSW as feedstock, and utilizing the end-products as near as possible. The case area is situated near the gas pipeline. The central location indicates many possible uses for the gas, in addition to the pipeline. On the other hand, the urban location it might make it challenging to find applications for digestate.

The Hiedanranta interview representation is displayed in **Table 6**. The city representative was familiar with Hiedanranta area and its development project, and thus, knowledgeable on both the opportunities and the challenges the case area offers. EcoFellows Ltd. is a nonprofit organization that produces information, guidance and educational and expert services on the field of sustainable living and development. The mere existence of such a company in the area indicates the rising importance of environmental values, and the company has also participated in the case area development. ELY-Centres are responsible for the regional implementation and development tasks of the central government. Covering both responsibilities of infrastructural development and environment and natural resources, ELY-Centers are an important collaboration partner, especially in the planning and land use planning phase. The city and the university have done collaboration concerning both the case area and sustainable economy from a broader perspective. The university has, for example, calculated the biogas production potential of the region.

Representation from fields of alternative sanitation and urban agriculture were also invited in this case interview, but could not be present due to scheduling difficulties. The broad expertise of the attended interviewees led to rich conversation, although the role of the digestate could have been discussed even more thoroughly.

3.1.2 Case Eco-Industrial Park - Kolmenkulma

The industrial case area Kolmenkulma is located in a junction of three municipalities: Nokia, Tampere and Ylöjärvi. Large municipal actors with steady feedstock flows of source-separated organic MSW and sewage sludge are planning to begin biogas production in the area. The case area also includes a vision of an Eco-industrial park, which is hoped to attract companies interested in material and energy recycling, and cleaner technology. These companies could add to the feedstock flow and find uses for the gas and digestate. The urban location and close proximity to the pipeline enable large scale biogas production, as the needed buffer for fluctuating supply and demand is ready, and possible customers are nearby.

In the interview, there was representation from the local waste treatment company, a premise development consultant company, ELY-Center and MTK. The waste treatment company saw possibilities in utilizing source-separated organic MSW in AD process. The development company has been active in the process, forming a so-called core with the water company and the MSW treating company, and also finding other collaborators to the industrial park, in addition to the three original system builders. The water company representation was unable to attend due to sudden changes in schedule, but with a message that the other system builder companies would be able to give an extensive image of the situation. MTK representation was present to give insight on the local farmers, and how they felt about collaboration possibilities. In addition to the interview, the companies brought material concerning the case, which has been utilized in the report as well.

From all the examined ecosystems, Kolmenkulma had progressed furthest in the ecosystem planning, and towards actualizing the production. Earlier in 2016, an investment decision had been made for the area, which ascertained the initiation of biogas production. At the time of the interview, the system builder companies had found five collaborating companies to join the eco-industrial park. The ecosystem had also received funding from the government Key Project fund. The goal is to begin the first stage during 2016-2019, which includes biogas production.

3.1.3 Case Agricultural Ecosystem - Hattula

The agricultural ecosystem is the municipality of Hattula that has recently shown great interest in renewable energy, including biogas production, and has a large concentration of animal farms. The gas pipeline goes near this case area as well. Biogas produced through AD has not been the only renewable the municipality has shown interest in - there has also been discussion of synthetic natural gas (Bio-SNG) production, for example. However, for the purpose of this thesis, the interview emphasized the system forming around AD process.

The biogas ecosystem idea had originated on a municipal level. The early stage of the case meant that definite plans had not yet been made. For these reasons, most of the interview representation was from the municipality, although municipal actors had found some possible collaboration partners. The three participating municipality representatives were in influential positions from where the biogas process could be advanced. They were also informed on the subject, as they had participated in the planning from the beginning. In addition to the municipality representatives, there was regional council representation, responsible from regional plan and areal planning. From these positions, there is a chance to affect regional planning, and otherwise promote the initiation of biogas production. The municipality had also applied for the government's Key Project funding, but had not yet received a decision for it, as the application was quite recent.

3.2 Material collection

The following chapter describes the used interview method, focus group interview, and the interview setting and structure. Material analysis process is also described. In addition to the interviews, data from the case areas was collected (project websites and information package one interviewee delivered concerning the Kolmenkulma case). This was not available in each case, which emphasizes the importance of the interviews.

3.2.1 Focus group interview method

The information on the cases and the actors was collected with **focus group interviews**. Focus group interviews are a qualitative information gathering method, which gets its name from focusing on certain individuals who are relevant to the case – the choosing method is also called **purposive sampling.** Focus groups are also moderately sized, typically 6 to 10 people – large enough to inspire conversation, but small enough to leave room for each individual and their thoughts in the recommended two-hour timeframe. Focus groups were chosen as gathering several people from the same case creates a possibility to gain synergies from the conversation. The method was also suitable as focus groups are typically loosely structured, which was a requirement, considering the research questions. And compared to individual interviews, focus groups are a much more time-efficient data collection method. (Yin, 2011)

The interviewees were chosen considering the participants' initial interest in the biogas process, aiming for a versatile representation of the entire biogas ecosystem from the feedstock supplier to the end-product users. In addition to purposive sampling, **snowball sampling** (Yin, 2011) was also practiced. This refers to the method where interviewees were asked to recommend other interviewees. In this case, actors that had agreed to be interviewed were asked which actors they thought would be vital to their case. This brought several suggestions for every case. Some of the recommendations were already in the invite list created by the researcher, but some new interesting suggestions arose as well.

Interviews were chosen as the primary data collection method of the projects because of the nature of the research questions. While trying to find reasons and motives behind actions and trying to solve how the collaborations between different actors come about, data collection from the actors themselves was mandatory. This kind of information is unlikely to end up documented even in finished projects, and all the cases in the thesis were still in a development stage. The interviews were chosen over surveys and other written questionnaire methods because of the quality and complexity of the questions. Discussion is more likely to offer more elaborate answers, and enables probing and follow-up -questions. Group interviews offer a chance to see how the different actors communicated and responded to each other's views on the matter. (Hirsjärvi & Hurme, 2008) Another positive quality of the group interviews was that gathering different actors together and creating an opportunity for a discussion worked as an incentive for participation.

3.2.2 The interview setting and structure

The researcher conducted the interviews. The interviewees were seated around a table, facing each other to encourage interaction, and the interviewer was seated amongst the interviewees. In the room, there were also two note-takers, in addition to the interviewees and the interviewer. The note-takers were seated at the side of the room, apart from the table. The note-takers were responsible for recording the interviews. Two recorders were used, to ensure the conversation was recovered, even in a case of technical difficulties. The roles of the note-takers were divided; one note-taker concentrated on matching speaker with each statement, in order to ease the transcribing. The second note-taker concentrated on the non-verbal communication and the atmosphere of the interview.

The interview setting and structure were deliberately informal. This was pursued in order to make the interviewees feel at ease and to encourage them to speak as freely as possible, as is recommended in literature. (Hirsjärvi & Hurme, 2008; Yin, 2011) To reach this effect, the word “interview” was avoided, for example. Instead, the researcher referred to a “group conversation” throughout the process. In the brief opening speech, the interviewer also emphasized there are no right or wrong answers, and that every opinion is valuable. The topic of the research was explained to the interviewees, but the details of the research questions were not disclosed. During the opening speech, the practices of the event were also explained: the role of the note-takers was introduced, and the hope that only one person would speak at a time, as the interview would be recorded, was expressed. Each focus group was led to the topic with a brief introduction, which followed the structure of the introduction of the thesis, explaining why biogas ecosystems are researched. To clarify the terms and to inspire the participants, a picture presenting possible components of biogas ecosystems and material streams (**Figure 4** translated into Finnish) was also displayed.

After that, the interviewees were asked a couple warm-up questions. Then, the interviewees were asked to imagine what a perfectly working biogas system would look like, in their point of view, and concerning the case in question. The interviewees were given a couple key words to help with the task, but they were reminded that they could also include elements that did not fit into these themes. After a couple minutes for individual thinking, these scenarios were then discussed. The interviewer had a checklist of topics that were interesting for the research, and questions prepared in case these topics were not covered. The goal was, however, to discuss the topics using mainly the utopia scenario and probe questions.

The goal of such a loose interview structure was to approach the interesting topics via the interviewee’s experience world, to get them speak freely and describe the process in as much detail as possible, and ask the research questions from the transcribed material, not the interviewees. By this, the researcher hoped to gather more genuine answers than by asking directly. For example, if asked about the motivators behind biogas interest, the interviewer would quite likely receive the same value list that can be read in the actor’s strategy. But via more elaborate storytelling and discussion, the interviewee hopefully explains in more detail which values were the most important, what awoke the initial interest, what was the triggering effect in the decision-making, and so on. The structure used is also less leading than direct questions, which makes the answers and conclusions more reliable.

The researcher did recognize that this kind of data collection method requires especial cooperation and openness from the participants. In the case the participants expected more structured and guided conversation, the interviewer also had themes and questions prepared. However, the researcher used very few back-up questions during the interviews, as the topics were covered so thoroughly while discussing the scenario. In fact, one group began discussing so eagerly after the warm-up questions that the utopia scenario was skipped completely. Although the utopia assignment was considered challenging, it did lead to elaborate conversation. In every interview, the participants were also so realistic that the interviewer did not need to steer the conversation away from the utopia and back to realism. Both the original structure of the conversation and the follow-up questions are displayed on **Appendix 1**.

3.2.3 Analysis phase

Right after every interview, the researcher had a debriefing session with the note-takers. In the debriefing sessions, the general atmosphere and the most prominent notions of the interview were discussed. The debriefing sessions also offered an opportunity to modify the structure of the interview, but in this research, both the interviewer and the note-takers felt the structure functioned well. After the debriefing session, the interview was transcribed as quickly as possible. The researcher did the transcriptions. After that, the researcher read the transcripts multiple times, in order to familiarize themselves with the material, which is recommended. The transcripts were then analyzed with *inductive content analysis*, which means the researcher did not have any ready assumptions or hypothesis. The analysis begun with open coding, which means commenting relevant parts of the text, and giving them headings at the same time. Headings were not predetermined, but instead, were generated freely during the process. After this, followed the abstraction, generating categories from the coding. Finally, the information these categories held were analyzed. (Elo & Kyngäs, 2008) This was done separately for every transcript, but very similar categories emerged, despite the differences in the cases.

Some of the formed categories could be easily linked to the research questions: the drivers behind the actors, ecosystem formation, and how the core relates to the ecosystem. These categories were also divided to subcategories, as many different aspects concerning these could be found from the transcriptions. Land use planning was also brought up as an essential factor in ecosystem formation in every interview. Other important categories that arose in two or all three interviews during the transcript analysis were the effect and changes of the current technological regime, and fossil fuels and fertilizers, for example. The categories were, in some cases overlapping, which meant that the categories could not function as a frame for analysis. However, each category relevant to the case is discussed in the following case chapters. Between the cases, there were also differences in the emphasis of the categories, and these differences were conveyed in the discussion by the weight they were given.

3.3 Sensitivity analysis

Because of the qualitative nature of the research, traditional requirements of reliability and validity created for quantitative research were not suitable for this study. For example, reliability can be defined as the ability to reach the same research result on separate occasions. Human beings are, however, changing over time, and several external circumstances might affect the mindset of the interviewee. This leads to the conclusion that interviews are never repeatable in a traditional sense, even if the interviewer and interview setting is otherwise similar. It also needs to be acknowledged that the researcher affects the data collection process, and that the conclusions drawn from the acquired material is their interpretation. Acknowledging this, and aiming to reach the thoughts and views of the interviewees as accurately as possible at the same time could be thus seen as a more suitable goal. (Hirsjärvi & Hurme, 2008)

This, again, can be pursued by limiting the reliability observation to smaller areas of the research. The interview structure, for example, is in an essential part of the research. It can either be successful, or undermine the research by leading the interviewees with value-loaded, pre-assuming or otherwise biased questions. The questions (Appendix A) were carefully formed so as to avoid this effect. In fact, the interview structure with the utopia scenario included very little direct questions, also reducing the risk of leading the interviewees. In addition to the question forming, there is also the recognized risk of the interviewees adjusting their answers, consciously or unconsciously, in the direction they imagine the interviewer wants to hear. In order to minimize this risk, the interviewer tried to remain neutral during the interview, by not conveying strong reactions, positive or negative, verbal or non-verbal, to the discussion heard. The purpose of the research was obviously explained to the interviewees, but again, to reduce the leading, research questions and all their details and follow-up questions were not explained in detail before the interviews. (Hirsjärvi & Hurme, 2008)

The group interview setting, in its fruitfulness, also has some specific challenges. First of all, large differences in the talkativeness of participants might compromise the desired outcome of receiving multiple different views in the same interview. Some participants might also feel uneasy to express their opinion in a group where other members have already shared their own, possibly contradictory, views. What is more, there is a risk of interviewees adopting an opinion from other interviewees unconsciously, if a member of the group is highly talented at argumentation. (Hirsjärvi & Hurme, 2008) While planning the interviews, these risks were acknowledged, and the interviewer aimed to minimize their effect. During the opening speech, the researcher emphasized that there are no right or wrong answers, and that every opinion is valuable. The time for individual thinking and writing before discussing the topics at length was also one way of ensuring everyone got their message across.

In the thesis, three focus group interviews, each addressing one potential biogas ecosystem, were researched. Yin (2011) suggests that three focus groups is the minimal amount, but depending on the case, even more could be recommended. Yin (2011) also reminds that when using small amount of data collection units, the generalization of the results should be done extremely cautiously, if at all. Industrial ecosystems are such varied that the generalizations were not a definite goal in the research in the first place. However, there could be found multiple similarities in motives and forming methods of the ecosystem, despite the differences between the studied cases. These could be assumed to be generalizable, to some extent.

4 RESULTS

All three case ecosystems were different in size, development stage and location. The interviews reflected these differences, and the emphasis of each discussion was rather different. However, it was surprising how many similarities amongst the different cases could be found in the analysis stage as well. This chapter gives a more in-depth analysis of each case, and the results summarizing the findings and answering the research questions will be presented in **Chapter 5**.

4.1 Case Hiedanranta

The City of Tampere, where the urban vanguard ecosystem Hiedanranta is situated, has already taken previous steps towards sustainable building and greener solutions, prior to the Hiedanranta area development. The interviewees recalled that similar goals had been set for recently-finished residential area Vuores in the suburbs. But despite the intentions, only a new waste collection system was implemented, and other solutions remained quite traditional. In the interview, it was contemplated that reasons for more traditional solutions were probably financial; the location of the suburb was not valuable enough to carry the more expensive alternate solutions. But on the other hand, the weight of the technological regime might also have been a factor. During the interview, the weight of the current regime, and how it cross-sections the entire operational field, was visible very clearly.

However, the pursuit of sustainable development has not been forgotten, and the case area offers a new possibility for piloting. The interviewees mentioned that typically, such centrally located areas in the city are sold in much smaller pieces, and are privately owned. The case area, however, is considerably larger than typical development areas. The city representative considered the act of purchasing the area as a clear message from the city that something radically new should be created. Both the close proximity to the city center and the nearby Näsijärvi lake increase the value of the area considerably, and this added value could carry the extra costs that piloting inevitably creates. These factors, combined with the fact that there is no ready infrastructure, mean the case area thus offers a rather unique opportunity for experimentation.

This being said, the challenge of the existing technological regime still remains. The effects of the regime, and challenges it brings to various different sectors of biogas chain were mentioned in the interview time and time again. For example, while discussing the energy structure, the weight of the existing regime could be seen especially clearly. Amongst the interviewees, and especially from the city representation, there was a vision and strong will to create a new, sustainable model that utilize renewable energy production in many different forms. But at the same time, the traditional solution felt tempting in its simplicity - “it feels difficult, and we have a good connection ready, the one hundred and ten (kV) power line…” The scheduling of the project– final decision should be made in a couple years – added to the pressure as well.

The concern is, obviously, justified. The interviewees had noticed the same challenge as the ST research: the effect of the current regime cross-sections every actor and aspect of the process (Geels, 2002). As the previous quote illustrates, even progressive decision-makers might feel some pull towards the safe and familiar solutions, and need to make an effort to leave their comfort zone to give the alternate solution the initial push. During the discussion, it was also noted that every actor along the way – designers, producers - is accustomed to the current regime, and creating something new requires more time, effort and money. The sustainable development expert also reminded that while the piloting itself requires finance, the existing structures need to be maintained and funded at the same time. And finally, it is not enough if these combined efforts result in a successful new solution – in the end, it is the consumer who eventually votes with their decisions. Mere green values are not enough, but instead, they need to reach the actions as well to make a difference. The sustainable development specialist phrased it quite accurately: “If we all practiced what we preached, the world would be very different already.” Research (Lakhan, 2016) also shows that even though the more sustainable choice, such as recycling, is considered positive, the change in behavior is very difficult to actualize.

The weight of the current regime was visible also when the discussion moved to the existing gas infrastructure. Many interviewees saw the locations of the pipeline and fueling stations as a strength, and as a natural backup opportunity. When discussing the Netherlands, which is currently aiming to reduce their natural gas usage and looking for alternatives, the interviewees were amazed how biogas had not come up as an option, as the infrastructure already supports gas utilization. On the other hand, some interviewees associated the gas grid so strongly with natural gas that they had not thought of the gas grid as an opportunity. Even traditional energy production methods, such as nuclear power, felt more intuitive backup solution – another reminder of the strength of the current technological regime based on large production units.

In addition to the current regime that resists change, another recognized challenge was the unpredictability of operational environment and the landscape. Oil price, for example, which strongly affects energy and fertilizer prices, cannot be predicted as it depends on complex geographical and political factors.

Combining residential area with industrial area brings its own challenges, and these were also addressed in the interview. The land use planning needs to be considered in every biogas system, but the close proximity of residential areas make the areal planning even more crucial. On one hand, there needs to be enough room – and room for expansion –

for the area to be appealing for industry. On the other hand, the industry cannot be situated in such a manner that it makes the area unappealing for residents. ELY-Center representative reminded that there are real possible issues when considering industry situated closely to residential areas, such as disturbing odour emissions and increased traffic. But, they continued, in addition to this, there are a lot of prejudices which may not all be based on reality, but affect peoples' behavior all the same. This makes them as real as any other challenge, and that is why they need to be addressed accordingly.

For the ecosystem formation, there were some suggestions and ideas, but no definite answers. What the participants considered important, in addition to enabling the system formation with the right kind of land use planning, was branding the area. A strong, positive image as a forerunner in sustainable solutions was considered attractive for both future residents and possible other actors. In Finland, there is already some food industry that get their energy from biogas produced from the organic waste they have produced – and they do utilize this in their advertising. (Bryggeri, 2016) "For residents, it could feel meaningful to be able to produce their own fuel, or gas to their stoves, to genuinely become part of the system", envisioned the university representative. And acknowledging where the feedstock is going could also help implementing the new practices the system might require from the users.

In the discussion, it was apparent that the clearest drivers were the environmental values. GHG emission reduction and improved nutrient recycling were mentioned several times. Financial aspects were mentioned as a framework, not as a motivation per se. Interviewees also emphasized the overall system optimization, not concentrating exclusively on the biogas part. For example, it was mentioned that the biogas production potential of feces was not that significant, compared to other available fractions – organic MSW, food industry waste and energy crops from landscape fields, for example - forming in the area. Including feces in the AD process also complicates the digestate utilization considerably. But it was noted that including feces in the AD process would have remarkable environmental effects through nutrient recycling and energy saving, especially with urine separation, low-water or waterless sanitation, and avoided central wastewater treatment. Thus, the fraction should not necessarily be excluded from the plans.

Use of gas as a vehicle fuel was recognized as an effective means for emission reduction. Nevertheless, even with the gas grid and two fueling stations nearby, the chicken-and-egg dilemma with fueling stations and gas vehicles was mentioned. It was also noted that if decentralized models like the presented case were to become more common, they could work as a partial solution for the chicken-and-egg dilemma by increasing local gas production. And the effect of the current regime arose with this subject as well: interviewees made the observation that people still associate vehicle fuels strongly with liquid fuels. Simply the difference between liquid and gaseous fuel might be one factor of why gas-fueled vehicles do not break through as easily. Another recognized reason for modest gas vehicle demand in the area was that the local bus company had had negative experiences with gas buses a decade ago. For the interviewees, it was unclear whether the gas bus malfunctioning had resulted from the gas, or from some other reason, unrelated to the fuel. However, it was noted that these kind of unsuccessful pilots were easily remembered, and that they affected people and decision-making, even stronger than the positive examples.

Another strong driver, partially linked to the environmental aspects, was the creation of new products – possibly even exports. With increased biogas usage, the environmental effects would obviously be multiplied. In this connection, constant interaction with research facilities and universities was emphasized. The recognized places for technological development were considered as an opportunity; for example, the model of the case itself, or some parts of it, could be commercialized. Quite recently, the city had also ordered a research concerning a large amount of old pulp mill residue in the area, and whether it would be suitable for AD process.

One important observation the interviewees made was that the calculated emission reduction potential of AD process compares the reduction potential to the current emissions. It was noted that as energy efficiency improves, and overall energy consumption begins to decline, the choice of energy source and the emissions it produces become more and more significant. An example from a biogas perspective: the feedstock volumes of Hiedanranta are not large enough to produce fuel for all the vehicles in the area – but as the university representative pointed out, this calculation has been made with current vehicle consumption and utilization. But as cars become more fuel-efficient, and new solutions like shared cars become more common, the same fuel amount will serve more people, increasing the significance of gas. The same effect is happening in other fields as well: new buildings require less heating, electrical appliances use less energy. The combined effects add up, increasing the importance and appeal of biogas and decentralized production.

4.2 Case Kolmenkulma

In the industrial case interview, there could be seen two major drivers behind the ecosystem formation. Firstly, the Town of Nokia has enabled the system with land use planning, by creating a platform where the ecosystem may be built. This has required significant investments from the town, which indicate the importance of the project to Nokia as well. Secondly, the three system builder companies are actualizing the opportunity the land use planning offers. But this means much more than simply utilizing the feedstock that happens to be the companies' responsibility, and making profit with the products. The companies have worked actively to find a best possible use for every waste fraction. At the time of the interview, final decisions for the system details had not yet been made, but for every option, there was a life cycle analysis, which included carbon footprint analysis and nutrient analysis. The planning of the system also considers environmental aspects by reverse engineering the process – first finding out where gas and digestate could be utilized, and then planning the biogas process according to that. This kind of thinking is obviously more demanding than the more traditional approach, and it may not lead to the most financially-profitable solution - but it is the only way to ensure best possible nutrient recycling, explained the development company representative.

The same logics was also applied while choosing the other companies in the ecosystem. The development company told they work as a kind of a loose filter, choosing the interested companies on the basis of how well they fit the other ecosystem, and if they genuinely bring additional value, in an environmental point of view.

The system builder companies also felt that the close proximity of the actors created considerable additional value. This enables easy material transfer with minimal traffic and emissions, which is essential to the ecosystem idea. Physical closeness also makes possible other synergies concerning electricity, heat and process steam utilization, for example. And in addition to these benefits, it also makes face-to-face meetings with ecosystem actors easy. Even from the short interview, it became apparent that unity between the companies was good. They told they met regularly, discussing future steps of the ecosystem, and solving together the challenges they had encounter.

The above-described unorthodox way of designing the process sends a clear message about the drivers behind actors. Environmental values were prioritized over financial profit if it meant a better overall utilization for every feedstock fraction and the process products, and better environmental effect overall. The environmental values have clearly been the towns interest while enabling the platform, and the companies have similar drivers. Both nutrient recycling and GHG emission reduction were mentioned multiple times. Another driver that was emphasized in this interview, stronger than in the other researched cases, was the research, and creating new innovations. What was noteworthy was the positive outlook the interviewees seemed to have on technological challenges and unsolved questions; they were regarded not as obstacles, but instead, as opportunities. The system builder companies envisioned that they could create an ecosystem model that could inspire other such collaborations in Finland, and abroad as well. At least in Finland, explained the development company representative, there are no ready examples of ecosystems that have the value chain utilized so completely, but an existing model could inspire others. And this way, the environmental effects would obviously be multiplied. In a wider timeframe, saw the system builder companies, this could even mean significant biogas amounts in the gas grid. The fueling stations and the gas infrastructure were considered a significant strength. Other alternative fuels besides biogas were also regarded very positively, as they reach for the same environmental effect; the development company representative told that part of the vision was a multi fuel -fueling station.

In this case interview, as well, challenges were recognized, in addition to the opportunities. The most prominent one was the Act of Public Contracts, and the limitations it sets to all public actors such as waste management companies and wastewater treatment companies. From EU-level, there has been set a limit that public actors may receive 20% of their revenue, at most, from sales to market-based actors. (HE 108/2016) Kolmenkulma companies saw this as a threat to optimal biogas ecosystem configurations: a public actor with large and steady feedstock flow might often be a natural initiator for biogas projects – and once the base volume is created, smaller commercial actors, who could not have the resources or volumes to begin the process themselves, could join with their feedstock. Unless, the Act of Public Contracts prevents it. Finnish legislation has plans to tighten the 20% limit even further (HE 108/2016), while other EU member countries have not seen the need for stricter limitations (Jätelaitosyhdistys, 2016). Obviously, this was a concern for Kolmenkulma actors - and a step in an opposite direction from the more flexible legislation that would benefit not only Kolmenkulma, but biogas ecosystems in general.

Another challenge was the digestate utilization. The interviewees considered field application an ideal solution, from the nutrient recycling point of view, but similar challenges were recognized as in other cases. On one hand, there are legislative limitations for both environmental and human health protection. On the other hand, there was serious concern of the image – even digestate from animal manure was considered a possible image risk, pointed out the MTK representative. Even with digestate suitable for fertilizing, farmers might be hesitant to use it, fearing that it would affect the consumers. Another reason for concern, explained the MTK representative, was soil contamination for a longer period of time, which would undermine the farmers' income, possibly for years. It was also noted that even though the content of the feedstock can be ascertained quite thoroughly with the current technology, the prejudice may still remain and affect the demand. The MTK representative also mentioned that the current environmental manager of MTK has taken a more cautious approach on the digestate fertilizer matter than the previous one, and this has also shifted the farmers' attitude towards digestate to a more cautious direction.

But Kolmenkulma companies have already begun searching for solutions. Inspired by the recent nutrient report of the region, the waste treatment company had ordered a survey on the nearby farmers and their interest in using digestate, or cultured digestate, as a fertilizer. The farm-specific mapping is meant to investigate how many farms would be interested in collaboration, and with which terms. The survey also aims to figure out specific reasons for hesitancy and if possible, find ways to make the digestate utilization more interesting. "Is it a question of money, or image, and can something be done, can the factor be improved – it can hinge on rather small details whether the digestate ends up in the field or not.", illustrated the waste treatment company representative. By getting an up-to-date and realistic view of the demand, the digestate processing is easier to design. Commercial fertilizer produced from the digestate was also envisioned – but technological development is required for this as well. One suggestion from MTK was to create a package deal of sorts from heat, electricity and digestate, if they are all produced in the ecosystem, and make it more appealing to the farmers like that. Yet another idea from MTK to make digestate-based fertilizers more appealing to the farmers was to treat the nutrient amounts unequally, in a way that would allow applying larger amounts of digestate-based fertilizers, compared to the fossil ones. Obviously, the environmental effects need to be considered as well.

Unpredictability of the landscape was a recognized challenge by these interviewees as well. An obvious example is the oil price, which strongly affects the landscape, but is unpredictable, as it depends on various factors beyond supply and demand. The MTK representative reminded that biomass-based energy production looked extremely good when the oil price was rising steadily. “There was every reason to assume it would continue rising - but it plunged instead. If we still were at 150 US dollars a barrel, we would not need any tariffs whatsoever, it would be profitable as it is.”

Also in this case, the importance of land use planning was recognized. The system builder companies told they had had initiative towards ELY-center, and recommended it to other future ecosystems as well. Currently, the land use planning in the industrial area enables building a second reactor, even though one reactor is sufficient for current volumes: “Just in case we need to expand more than we estimate possible now.” But obviously, land use planning can also complicate the ecosystem formation. “If the land use planning is too tight, the industry will go someplace else – even somewhere other than Finland.”, reminded the ELY-center representative. This way, not only the synergies brought by the system would be lost, but also domestic production, and technological development it might inspire. Thus, land use planning can either have an encouraging, or hindering, effect on the ecosystem formation.

Yet another notion the interviewees made was the importance of municipal actors. In this case, the town has worked as an enabler by creating the platform, but the interviewees reminded that they had other affecting possibilities as well. For example, in this case, the inhabitants of Nokia play an important role, e.g. through source separating the waste, and the town is in a key position to affect the citizens. The interviewees hoped that making the inhabitants realize they are an important part of the cycle would be more effective than just explaining which fraction goes to each bin. And thus, by taking an interest and an active role in the biogas ecosystem, the town can significantly aid the system. The interviewees also saw that municipal actors are in a key position to promote gas vehicles and make them more visible, with public transportation, for example. And there was a hope that the town would also benefit from the green image.

4.3 Case Hattula

The agricultural case ecosystem was still in a planning stage, and thus, the ecosystem formation and how the suitable actors could be found were still open questions. Also here, creating a strong, environmentally-friendly brand was seen as a good way for attracting suitable actors. The interviewees also recognized the need to anticipate and take the project into consideration in land use planning. It was noted that the entire ecosystem could not be planned beforehand – but that a bigger company could create the base volume, and act as a system builder, and other actors could later join the ecosystem. For the role of a system builder, larger commercial actors with enough resources for initial investments were seen as possible enablers. It was also noted that current field of operation would not need to limit the possible system builders, if there only were interest in biogas. For example, forest product companies were seen as one possibility.

What the interviewees saw as a challenge was to find actors that would be able to optimize the entire biogas production process from the natural resources and environmental point of view. Some interviewees feared that market-based actors might, instead, only optimize smaller part of the biogas process – the part that would give them the most profit. One suggested possibility was to find a multidisciplinary company to act in a major role, and by this, reduce the risk of optimizing smaller parts. But obviously, such an actor would not be guaranteed to be found. A collaboration of multiple actors was also seen as a more probable environment for innovation than one single actor. Again, it was reminded that branding could work as a tool to find suitable actors who shared the goals of the municipality, and who would also implement the values in the ecosystem. This being said, it was noted that in order to create the ecosystem attractive for each actor, it would also have to be interesting and financially profitable for every actor. Fitting these both pieces in the equation would not necessarily be simple, but it was suggested that sustainability and environmental values could be implemented into the equation from the landscape level, and thus, they could steer the market-based decisions.

Very much like in other cases, the environmental drivers were clearly visible throughout the interview. Already during the warm-up question, which did not include any mention about values, personal environmental values were mentioned by most interviewees. A lot has changed in a few decades; as one interviewee described, they used to visit eco-village pilots during their studies in the 80's, and then, they were a peculiarity. But today, sustainable development is such an important goal that it is incorporated in legislation. One municipality representative reminded that motivation can be found as near as in the first section of the Finnish Local Government Act: "Municipalities shall strive to advance the well-being of their residents and promote sustainable development in their respective areas - -Just think about it, in the first section!" Keeping that in mind, reaching for local, sustainable solutions like biogas ecosystems feels quite natural. There was a goal that ecosystem could also contribute to the well-being of the residents and promote the regional economy in general, by increasing local production and creating jobs, for example.

The interviewees found even more reasons for increasing local production, in addition to job-creation, enlivening the area, and reducing transportation emissions. Yet one more argument for locally-produced electricity, fuel and fertilizers was to reduce the dependency we now have on the imported versions. Again, it was reminded that supply and price depend on political situation, in addition to the resource sufficiency. The uncertainty this creates was considered challenging, and the concern was even more pronounced than in other interviews, although it was visible in all of them.

Importance of research and technological development was recalled in several instances. For example, it was reminded that the AD processing attempts for reed canary grass have not been very successful in Finland. The interviewees saw this as an opportunity for future research, not as a discouragement for energy crop cultivation. It was also noted that food cultivation and energy crop cultivation have quite different requirements, which made the possibility of energy crop technology development even more interesting. Energy crops can be harvested several times a summer, they require less maintenance, and can be harvested wet, which simplifies things as well. As long as all the field area is not needed for food production – like currently in Finland – this possibility should be pursued, saw the interviewees. Hattula representatives also saw an interesting object for future research in Glyceria Maxima, an invasive species that has spread widely in the nearby Vanajavesi lake. Utilizing the plant in AD process would serve both goals of protecting the lake and producing energy.

In this interview, digestate field application was seen as a natural choice, and participants did not expect any prejudice towards the product, as long as legislative requirements were met. On the contrary, it was reckoned that the farmers might be very eager to utilize alternatives, if their price were even slightly lower than that of fossil fertilizers – the challenging economic situation has affected farmers as well. To minimize the costs, it was noted that the amount of actors in the chain should be minimized. Guaranteeing a low-enough price for digestate-based fertilizers was not considered problematic, as the fossil fertilizer prices will most probably rise. On the other hand, it was seen that in the future, with sufficient technology, the degree of upgrading could add both value and demand for digestate-based fertilizers considerably.

The gas infrastructure in the area was such a self-evident strength for the interviewees that the follow-up question of its utilization seemed even redundant: “Well, there is already some (biogas) in the grid - it is the same methane.” It was clear for the interviewees that if they utilized the gas grid in the future, they would prefer it to be a two-way street: both the possibility to purchase gas when needed, and to sell the gas in the grid while the local demand slowed down. This would also increase the overall biogas content in the grid, especially if the practice became more common, which was considered a good goal. However, as mentioned above, the natural gas and its origin as an imported, fossil fuel was considered somewhat problematic.

The unpredictability of the operational environment was considered a major challenge. It is safe to assume that AD technologies develop in the near future – but how the national and international regulations and subsidies respond to these changes, and how quickly, is quite impossible to predict. It is clear that there is a will to promote biogas systems amongst other renewables, but finding the correct measures for this is not simple. Even though bioeconomy is one of Key Projects in the government program, the interviewees felt that more could be done in Finland. “Now, it depends on small, separate actors.”

5 DISCUSSION

With case analysis, the supporting documents and the background theory, answers to the research questions were formed. First, drivers and ecosystem formation will be discussed. Then, the effect of the gas core to the ecosystem formation will be viewed. And last, there will be some suggestions for how the ecosystem formation could be progressed in Finland.

5.1 Drivers and ecosystem formation

First part of the research question concerned the formation and actors of biogas-linked industrial ecosystems. The purpose was to find out what drives different actors to form biogas collaborations – and how exactly these collaborations form and develop. On **Table 7**, the most important drivers for each ecosystem are listed. The list aims to arrange the drivers by the importance, placing the most important driver highest – as the drivers behind each case were surprisingly similar, their emphasis and reasons set the cases apart. The drivers will be discussed in more detail in the text below.

Table 7*. The most important recognized drivers behind the case ecosystems.*

Case	Drivers
Hiedanranta	**Environmental protection**
	- Waste minimization, zero-waste, circular economy
	- Towards flexible, decentralized energy production
	Technological development
	- Piloting radically new, sustainable solutions
	Suitable area and location for piloting
	- Existing infrastructure does not create limitations
	- Location of the area is valuable enough to carry the piloting costs
	- Gas infrastructure offers backup opportunity
Kolmenkulma	**Environmental protection**
	- Best use for every feedstock fraction, entire ecosystem optimization
	- Nutrient recycling and nutrient neutrality, no eutrophication of the Baltic sea
	Technological development
	- Creating an example ecosystem to inspire others
	- Creating exports, collaboration with research facilities
	Suitable area and location for a larger ecosystem
	- Land use planning enables physical closeness and room for growth
	- Nearby-located gas grid and fueling stations

	Reducing dependency on imported fossil fuels and fertilizers
Hattula	**Environmental protection** - Best policy for waste management – “cleaning away” the feedstock fractions - Well-being of the residents - Entire ecosystem optimization - Lake Vanajavesi protection - Responsibility from legislation **Increasing local production** - Enlivening the rural area, creating jobs - Reducing dependency on imported fossil fuels and fertilizers **Technological development** - Possibilities in energy crop technology and commercial biofertilizers

From all the case systems and actors, there could be seen one strong, common driver: environmental values, and willingness to actualize them. GHG emission reduction and environmental protection via nutrient recycling were mentioned in every interview. Waste minimization, utilization, and best possible practice for each feedstock fraction – goal was recalled in every interview.

On the contrary, it was almost surprising to see how little the financial factors seemed to be affecting the decision-making. In every case, money needed to be considered, naturally, but it was not the driving force behind the change. It seemed more like the financial facts set some kind of frames and limitations for action, but inside these frames, the overall goal was environmental protection - even if it meant reduction in the profit. In every interview, it became apparent that some financially profitable solutions had been, or would be rejected because of their environmental effects. One example of this kind of practice was the idea to create two separate digesters for different types of feedstock, if the qualities of some feedstock meant that digestate would not be suitable for fertilizing use.

Another common denominator for the actors was a positive outlook on research, readiness to collaborate with research facilities, and confidence in technological development that would contribute to biogas system development in the near future. This driver goes hand in hand with another common denominator: the shared strong will to increase local production on both energy and fertilizers – and reduce the dependency on imported energy sources and fertilizers. Partly, this can be seen as an environmental act as well – reduced transportation distances create less emissions, and if the new practices generalize, the environmental effects will be multiplied. But possibly even more importantly, this was seen as a means to increase local employment and well-being and enliven the area.

The formation of the biogas ecosystem, and finding the right actors, was considered somewhat challenging in the cases that had not yet actualized their plans. Several interviewees suggested that creating a positive brand and emphasizing the environmental effects would be a good way of attracting suitable actors. And viewing the above-listed values that drive the participated actors, this seems like a good approach. The actors need to share the environmental values to create a system that reaches for overall benefit, instead of targeting optimization of smaller units.

In ST-research, the importance of social aspects was emphasized. (Ollson & Fallde, 2015) Even in the studies concentrating on other aspects of ST-transitions, the social aspects arose to an important role. (Cavicchi, 2016) The same emphasis was also seen in the interviews. With tight and active collaboration, challenges could be solved more efficiently – and optimization of only smaller units could be avoided. Openness in collaboration is also a good way to ensure the ecosystem is interesting for every actor – which is mandatory for long-term success.

Every case representation had come to the conclusion that the biogas ecosystem could not be planned completely beforehand – and the ecosystem research has shown similar results. (Lowe & Evans, 1995; Ollson & Fallde, 2015) The actors in these cases had, however, found means to promote ecosystem formation, in addition to the brand creation. First and foremost, the systems need to be enabled with land use planning. A large enough space for multiple actors – and room for expansion – is crucial for the system to be attractive for actors, and to reach the various benefits the physical proximity creates. After that, a system builder – whether it is one company or a close collaboration of a few, or even an influential individual – is recommended to create a basis for the operation. After the initial investment has been made and basal feedstock mass flow secured, other actors have a much smaller threshold to join in and increase the production. This, of course, requires adaptability from the system: the technical aspects need to be scalable to some extent, the land use planning will need to have room for new actors – and the system builders need to be open to new collaboration as well. And if the actors are public, The Act of Public Contracts brings its own limitations which need to be considered.

5.2 Role of existing gas infrastructure

Another part of the research question was whether the existing core – gas pipeline, biogas production plant, or other existing biogas activity that could work as a backup – affects the ecosystem formation, and how. All examined case ecosystems were located close to the gas grid, which functions as a core in these cases. In all three cases, the gas grid was seen as a great strength and an opportunity, as the need for backup was recognized. In the interviews, it was also emphasized that ideally, the connection would work in both directions; that gas could be both purchased from, and sold into, the grid. It is difficult to assess whether the ecosystems would have begun forming without the backup opportunity the pipeline offers – but undoubtedly, the pipeline has been a positive driver. But what was also noted was the fact that the image of gas grid is strongly associated with natural gas. Combined with the strong shared will to reduce dependency from fossil fuels, this might affect the ability to consider the backup opportunity the gas grid offers.

The fact that all the examined case ecosystems were located close to the natural gas grid obviously means the sample is somewhat limited. More conclusive results could be gained by including cases with different kind of cores. For example, a larger biogas production unit might be able to work as a backup, but it might also awaken concern for feedstock availability. Even in some interviews, there was apprehension about other possible biogas activity in the nearby area, and the effect it would have on feedstock sufficiency. Based on this, it seems that the overall effect of the core on a satellite ecosystem formation might also be negative, even, and the type of the core is rather significant.

This part of the research question could also be examined more thoroughly by including case systems that are not located close to any kind of core. One such ecosystem was included in the original research plan but, as the original case was not realized, this resulted in all case ecosystems locating near a core. Yet another interesting research subject would be to examine promising ecosystem locations and interested actors that have not realized their plans. These would obviously be more challenging to locate, but they would undoubtedly offer valuable insight on the hinderers behind ecosystem formation.

5.3 Increasing biogas production

Even though the interviewees had a positive outlook on future and research, the weight of the current ST-regime, and the choosing pressure it creates, were present in all studied cases. There was also concern of how the operational environment will develop in the future, and if the legislation would be able to follow this development and support biogas production effectively. Two previous chapters presented enablers and drivers behind ecosystem formation, but this chapter discusses biogas promotion from a broader perspective.

Firstly, ST-transition theory suggests that shielding measures should be targeted towards every possible aspect of the ST-regime, and as versatile as possible, to have a maximum effect. (Smith & Raven, 2012) But at the moment, the shielding measures in Finland are targeting practically solely the technological aspect of the ST-regime, and production, to be precise (Chapter 2.3.3). Broadening the shielding measures towards other aspects – for example consumer practices, infrastructure, and symbolic meaning of the technology – could be an effective means towards realizing the potential biogas systems hold. There are also examples of how too narrow shielding measures can even have a negative effect, instead of simply being ineffective (Cavicchi, 2016; Edwards et al., 2015).

Positive examples are, however, more interesting: Sweden has good examples of consumer-targeted shielding: Sweden promotes gas vehicles by free parking, exemption from the congestion charge, and lower taxation (Engdahl, 2010). And even though the Finnish gas vehicle taxation has been brought to a more reasonable level, Mutikainen et al. (2016) point out that the motive power tax of gas-fueled cars is still considerably higher than that of electric cars or gasoline hybrids. What is more, it does not separate natural gas from biogas, but instead, assumes all gas vehicles run on natural gas (Mutikainen et al., 2016). From this, it could be deduced that the strength of the current regime has affected the legislation as well, resulting in less-than-optimal shielding measures. But noticing the improvement points is the first step on the path towards more effective shielding.

Geels (2002) recognizes the symbolic meaning of the technology as an important aspect of the ST-regime – but since there are other aspects that are much more concrete, noticing this is not in any way self-evident. Every interview group did, however, see branding as a powerful tool for both system building and general biogas promotion. As there are already companies that utilize biogas and have also made it visible in their advertising (Bryggeri, 2016), it would be worth researching whether this has affected the company image – or even consumer behavior. Research indicates (Lakhan, 2016) that while people want to make environmentally friendly choices, behavioral changes are difficult to make, and that is why these intentions do not necessarily actualize. But, as the interviewees suggested, making these choices very easy could help actualizing them. And one way for that could be creating a strong brand and making biogas visible that way. Visibility was found to be a key element in creating behavioral change in Lakhan's (2016) study – even more important than easiness of the choice.

Infrastructure is yet another aspect of the ST-regime that is currently outside the shielding measures. In many interviews, the chicken-and-egg dilemma concerning gas vehicles and fueling stations was mentioned. Investment support towards fueling stations would be easy and direct act - and supporting decentralized gas production would support vehicle fuel production as well, creating a kind of positive cycle.

In addition to creating a protective space with shielding measures, the shifts in ST-regime could be aided with creating pressure from the landscape level. In every case, the interviewees felt this was necessary in Finland, and could be enforced by legislation. The interviewees also expressed that current shielding measures should be simplified. For example, investment support and feed-in tariff exclude each other, which means that the producer should be able to predict the volumes beforehand. Because of this, scaling up might, in some cases, be financially unprofitable, even though additional digestate would be available. As both the industrial ecosystem research (Korhonen & Snäkin, 2005; Lowe & Evans, 1995) and interviews suggest, the ecosystems cannot be completely planned beforehand. As flexibility and adaptability are key elements in ecosystem formation, the shielding measures – such as the mentioned legislation – should also support this kind of creative and flexible formation. Some of these structures – like the above-mentioned limitation - come from the EU-level (Mutikainen et al., 2016), which obviously makes the affecting on them much more challenging.

Some of the legislation that might discourage biogas production or promote fossil fuel usage are, however, from a government level. As they are undoubtedly challenging to alter, it will still be easier and faster than affecting the EU-level. For example, there is no feed-in tariff available for producing biogas for vehicle use, and as the calculations in the theory part illustrate, the best possible emission reduction could be gained by vehicle use. At the same time, the interviewees reminded, there are structures that encourage farmers investing in harvesting equipment that run on oil – the intention has undoubtedly been to support local food production, but emissions have not been considered. The interviews and Mutikainen et al. (2016) also found many other examples of structures that still promote the fossil fuel and fertilizer usage – and also concrete examples of how biogas production could be promoted. **Table 8** presents some examples of shielding measures that would better help covering the entire ST-regime. The division to seven aspects is created by Geels (2002), and the examples are collected from the interview analysis and Sitra-report (Mutikainen et al., 2016).

Table 8*. Examples of shielding measures for biogas ecosystem and biogas production and utilization promotion, targeting different aspects of the regime. (Geels (2002); Mutikainen et al. (2016); the interviews)*

Aspect of the regime	Shielding measure
User practices and markets	**Making gas cars more appealing for private users** - Tax reliefs, cheaper or free parking, priority lanes etc. for gas cars **Increasing biogas visibility** - Offering information on recycling and how it affects biogas process - Choosing biogas on a municipal level, e.g. waste transport and public transport - Increasing the supply of products that utilize biogas in production
Infrastructure	**Investment supports for fueling stations and gas purification units** - Encouragement for creating new fueling stations - Implementing gas fueling alternative in existing stations with services and other fuels **Encouragement for local pipeline building**
Symbolic meaning of technology	**Brand creation and visibility for biogas** - Systematic work for biogas promotion to create visibility, preferably from government level
Industry structure	**Encouraging industry for gas vehicle usage** - Making gas vehicles more appealing as company cars and as working tools **Encouraging industry actors to form biogas-linked collaborations**
Technology	**Research in various different aspects of production and utilization** - Digestate refinement and biofertilizers, alternate sanitation, Bio-SNG, industrial ecosystem formation…
Policy	**Increasing flexibility in production and utilization** - Recognizing and dissembling the hindering structures - Feed-in tariff for vehicle fuel production

	- More flexible loan terms for renewable energy projects
Techno-scientific knowledge	**Implementing biogas and sustainable solutions in education** - Agricultural education, mechanics, energy technology… **Offering information and education to interested small producers**

As can be noted, some of the measures in **Table 8** might be interlinked, and concern both user practices and symbolic meaning of the technology, for example. However, the table emphasizes that the measures could be significantly broader than they currently are. And even though the shielding measures are easily first associated with financial incentives and subsidies, the measures do not need to be limited to these: the meaning of education in various different fields was emphasized in Sitra report (Mutikainen et al., 2016). It also needs to be noted that financial incentives do not necessarily need to cost money; they can also work the other way, by rising the taxation of the dominant, less sustainable technology, for example. The GHG emission reduction calculation of Pirkanmaa presented in **Chapter 2** could also give some suggestions to where would be a good place to start: over 75 % of Pirkanmaa feedstock potential lies in agriculture.

In the interviews, it was also noted that AD systems should, eventually, be stand-alone financially – which is the ultimate goal in ST-transitions (Geels, 2002). The financial shielding measures should be able to be removed, after the new technology is developed enough to survive without them – or after the regime is changed enough to support the new technology. In biogas perspective, it is quite impossible to say which will need to change; the result will probably be some combination of both. Before this can be reached, the technological development the interviewees underlined is needed. Probably even more importantly, the shift will need to reach user practices, and for that, other shielding measures – such as brand creation - are essential.

The Finnish circumstances – the sparse population density, and thus scattered feedstock flow potential (Tilastokeskus, 2015b) – already mean that economical biogas units are challenging to form. If the goals for biogas promotion want to be reached, biogas ecosystems do still need shielding measures before they reach complete technological maturity. In summary, the shielding measures should be reviewed and updated to match the flexibility that is typical for biogas ecosystems – and the shielding measures should cover as many aspects of the ST-regime as possible.

The question of who should take the responsibility for the shielding should also be addressed. **Table 8** in its versatility indicates that no one actor can take the entire responsibility, but instead, biogas shielding should be a group effort. Legislative measures were considered a good way towards creating pressure for change, both by the interviewees and ST-theory (Geels, 2002), and that should be continued. As the studied cases demonstrated, the current legislation was one driver for public actors and municipalities to reach for more sustainable structures. However, the interviewees also recognized the possibility of market-based actors to contribute to biogas systems, and especially, act as system builders.

And lastly, but definitely not less importantly than other observations considering biogas ecosystems: in addition to renewability, GHG emission reduction potential is a strong driver for every discussed case in the thesis – and other studied cases in previous research as well (Kiviluoma-Leskelä, 2010). In the light of the example calculation made from Pirkanmaa region, the emission reduction potential of biogas (less than 7% with every utilization method) does not seem that momentous. But it needs to be noted that this value is based on current emissions, and assuming current effectiveness of end-use technologies. As the urban case interview brought up, greener solutions are searched for in every field. As energy is saved in every aspect of living, the origin and emissions of utilized energy becomes more and more significant.

6 CONCLUSIONS

This thesis studied biogas ecosystems and their formation. Already the theory on industrial ecosystems indicates that the uniqueness of industrial ecosystems – and thus biogas ecosystem – makes them very difficult to plan, or replicate to another location. The focus group interviews from three studied case ecosystems shared this view. However, the research investigated whether there can be found similarities in formation of such systems, or similar drivers behind the actors. Even if the system formation cannot be planned, understanding the drivers and formation process might be able to assist in biogas promotion.

From the three cases that considerably varied in size, available feedstock, location and other attributes, surprisingly similar drivers for ecosystem formation could be found. The most prominent one was the environmental protection, which was very visible in every interview. GHG emission reduction and nutrient recycling clearly guided the decisions towards more sustainable direction, even at the cost of financial profit. Optimizing the entire value chain, not only the biogas production, was emphasized in each case. Secondly, the participants wanted to reduce the dependency on imported energy sources and fertilizers, and increase local production. Interest in research and development, and collaboration with research facilities was also considered important.

Three key elements for promoting the ecosystem formation were recognized. Firstly, the ecosystem needs to be enabled from the municipal level by land use planning. Physical closeness was considered essential for the actors to find synergies in material and energy usage, but also to interact effectively. Possibility to grow was also important, to both make the ecosystems attractive for actors, and to enable best possible use for every possible feedstock fraction and the products. Secondly, ecosystem actors need to share similar values, recognized in the previous paragraph, to be able to reach for overall system optimization. It was suggested that brand creation could be one means to find the actors that shared similar values. Thirdly, a strong system builder is usually needed. A large company, or companies, could work as initiators and enablers, creating the base for operation, and enabling. Smaller actors may not be in a positions to make the initial investments, even though the interest is there.

In every studied case, the gas pipeline was situated nearby. The interviewees considered this a great strength, as the gas supply and demand undoubtedly require some kind of buffer. Ideally, the participants saw the collaboration as a two-way street: gas should be able to be both purchased from, and sold into, the pipeline. The challenge, however, was that the pipeline was so strongly associated with natural gas. Reducing the dependency on fossil fuels was a driver for all ecosystems, and thus, natural gas was considered something to be avoided. Obviously, injecting AD-produced gas in the gas grid reduces the amount of natural gas needed, but the possibility needs to be recognized. Other kind of cores besides the pipeline were not observed in this study, but depending on the type of the core, the results could be different.

ST-research indicates that niche innovations – such as biogas ecosystems – require shielding measures in order to push through and become a lasting part of the technological regime. The observation of current biogas shielding measures, the current biogas production rate and biogas production and utilization goals in Finland indicate that the current measures are not effective enough. Selection pressure of the current regime was also emphasized in the interviews. As both the interviews and ST-studies indicate, it is difficult to plan biogas ecosystems beforehand, and in order to reach the best possible configuration, they should be able to build up little by little. Current shielding measures were considered rigid, but more flexible shielding measures would support this kind of flexible development. What is more, the shielding measures should be targeted towards various different aspects of the ST-regime, such as user practices, infrastructure and symbolic meaning of the technology – in addition to the technology itself. In addition to renewing the shielding measures, pressure for change could also be created from the landscape level with legislation. Moreover, while reviewing and renewing the shielding measures, it should be remembered that a substantial part of the feedstock volumes lies in agriculture, as the Pirkanmaa calculation indicates. And finally, the emission reduction potential calculations were done assuming current effectiveness of energy utilization. As this will most likely improve in the future, it will also increase the significance of biogas production.

REFERENCES

Abbasi, T., Tauseef, S.M., Abbasi, S.A. (2012). Biogas Energy. Springer New York, London

Benjaminsson, J. & Benjaminsson, G, Gasefuels AB (2013). Samverkanskoncept för biogasproduktion inom lantbruket, Minimering av risker I realiserad project. WWW, available: http://www.biogasost.se/Portals/0/Rapporter/Samverkanskoncept_lantbruket_slutrapport.pdf (18.3.2016)

Bouwman, A.F., Beusen, A.H.W., Billen, G (2009). Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050. Global Biogeochemical Cycles 23, 4.

Bryggeri (2016). Bryggeri panee oluensa biokaasulla. WWW, available: http://bryggeri.fi/bryggeri-panee-oluensa-biokaasulla/ (20.7.2016)

Cavicchi, B. (2016). Sustainability that backfires: the case of biogas in Emilia Romagna. Environmental Innovation and Societal Transitions. WWW, available: http://www.sciencedirect.com/science/article/pii/S2210422416300223?np=y (15.9.2016)

Edwards, J., Othman, M., Burn, S. (2015). A review of policy drivers and barriers for the use of anaerobic digestion in Europe, the United States and Australia. Renewable and Sustainable Energy Reviews 52, 815-828.

Elo, S. & Kyngäs, H. (2008). The qualitative content analysis process. Journal of advanced nursing 62, 1, 107-115.

Energiateollisuus (2016). Sähkön käyttö ja käyttäjämäärät maakunnittain, Year 2014. WWW, available: http://energia.fi/tilastot-ja-julkaisut/sahkotilastot/sahkonkulutus/sahkon-kaytto-maakunnittain (16.3.2016)

Energiavirasto (2015). Kertomus maakaasun toimitusvarmuudesta 2015. WWW, available: https://www.energiavirasto.fi/documents/10191/0/Kertomus+maakaasun+toimitusvarmuudesta+2015.pdf/b54544fd-6f8e-4c1d-a665-e1913b483917 (31.8.2016)

Engdahl, K. (2010). Biogas policies, incentives and barriers - a survey of the strategies of three European countries. Lund University, Lund, 2010

Fallde, M. & Eklund, M. (2015). Towards a sustainable socio-technical system of biogas for transport: the case of the city of Linköping in Sweden, Journal of Cleaner Production 98, 17-28.

Gasum (2016a): Suomen kaasuverkosto. WWW, available: http://gasum.fi/siirtoportaali/Suomen-Kaasuverkosto/ (28.7.2016)

Gasum (2016b): Biokaasu. WWW, available: http://gasum.fi/Kaasutietoutta/Biokaasu/ (28.7.2016)

Gasum (2016c): Maakaasun käyttö Suomessa. WWW, available: http://gasum.fi/Kaasu-tietoutta/Maakaasu/Maakaasun-kaytto/ (28.7.2016)

Gasum (2016d): Porin terminaali. WWW, available: http://gasum.fi/Tietoa_Gasumista/Skangas/Porin-terminaali/ (28.7.2016)

Gasum kuvapankki (2016): Gas networks and infographs. WWW, available: http://gal-lery.gasum.fi/section/gas_networks_and_infographs/ (16.3.2016)

Gasum Oy (2016): Map of Finnish gas grid.

Gasum (2015): Gasumin uutiskirje 3/2015. Tavoite: 35 uutta Gasumin tankkausasemaa Suomeen. WWW, available: http://www.puhtaampiliikenne.fi/uutinen/tavoite-35-uutta-gasumin-tankkausasemaa-suomeen.html (11.8.2016)

Gasum Vuosikertomus 2014 (2014). WWW, available: http://gasum.fi/globalas-sets/vuosikertomukset/gasum_vsk14_fi_aukeamittain_144dpi_010415_linkit.pdf (17.9.2016)

Geels, F.W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Research Policy Vol. 31(8–9), pp. 1257-1274.

Hallvar, A. (2014). Varsinais-Suomen biomassapotentiaalien hyödyntäminen energian-tuotannossa. Raportteja 210, Turun ammattikorkeakoulu, Suomen Yliopistopaino – Juve-nes Print Oy, Tampere.

HE 108/2016 vp (2016). Hallituksen esitys eduskunnalle hankintamenettelyä koskevaksi lainsäädännöksi. WWW, available: https://www.eduskunta.fi/FI/vaski/HallituksenE-sitys/Sivut/HE_108+2016.aspx (1.9.2016)

Hirsjärvi, S & Hurme, H. (2008). Tutkimushaastattelu – Teemahaastattelun teoriat ja käy-tännöt. Helsinki Universty press Gaudeamus, Helsinki.

Huttunen M.J., Kuittinen, V. (2015). Suomen biokaasulaitosrekisteri n:o 18, Tiedot vuo-delta 2014. University of Eastern Finland, Reports and studies in Forestry and Natural Sciences 21, Grano Oy, Joensuu.

Huttunen M.J., Kuittinen, V. (2011). Suomen biokaasulaitosrekisteri n:o 14, Tiedot vuo-delta 2010. University of Eastern Finland, Reports and studies in Forestry and Natural Sciences, Kopijyvä Oy, Joensuu.

IEA Bioenergy (2016a): Task 37 publications – success stories. WWW, available: http://www.iea-biogas.net/success-stories.html (29.3.1016)

IEA Bioenergy (2016b): Task 37 publications – Case studies. WWW, available: http://www.iea-biogas.net/case-studies.html (18.9.2016)

Jätelaitosyhdistys (2016): Tiedote: Hallituksen toimet nostavat jätemaksuja. WWW, available: http://jly.fi/tiedote.php?tiedote2_id=534 (1.9.2016)

Kiviluoma-Leskelä, L. (2010). Biokaasun tuottaminen ja hyödyntäminen Lappeenrannassa. Lappeenrannan teknillinen yliopisto, diplomityö, 122 p.

Korhonen, J. & Snäkin, J. (2005). Analysing the evolution of industrial ecosystems: concepts and application, Ecological Economics 52(2), 169-186.

KTM 5/2003 Uusiutuvan energian edistämisohjelma 2003 – 2006 Työryhmän ehdotus. Kauppa- ja teollisuusministeriön työryhmä- ja toimikuntaraportteja 5/2003. Kauppa- ja teollisuusministeriö. Uusiutuvan energian työryhmä: puheenjohtaja Erkki Eskola, sihteeri Nina Broadstreet ja Jukka Saarinen. Edita Publishing Oy ISBN 951-739-718-6. 56 s.

Kymäläinen, M. & Pakarinen, O. (ed.) (2015). Biokaasuteknologia –raaka-aineet, prosessointi ja lopputuotteiden hyödyntäminen. Hämeenlinna, Hämeen ammattikorkeakoulu. 208 p.

Lakhan, C. (2016). Out of sight, out of mind: Issues and obstacles to recycling in Ontario's multi residential buildings, Resources, Conservation and Recycling 108, 1-9.

Lowe, E.A. & Evans, L.K. (1995). Industrial ecology and industrial ecosystems, Journal of Cleaner Production 3(1–2), 47-53.

Nelson, R.R., Winter, S.G., (1982). An Evolutionary Theory of Economic Change. Belknap Press, Cambridge, MA.

Maanmittauslaitos (2016). Map of Pirkanmaa and Häme regions and the gas pipeline. Maanmittauslaitos lupa nro. 011/MML/13

Mokhatab, S. & Poe, W.A. (2012). Chapter 1 - Natural Gas Fundamentals, in: Poe, S.M.A. (ed.), Handbook of Natural Gas Transmission and Processing (Second Edition), Gulf Professional Publishing, Boston, 1-42.

Motiva (2010). Polttoaineiden lämpöarvot, hyötysuhteet ja hiilidioksidin ominaispäästökertoimet sekä energian hinnat. WWW, available: http://www.motiva.fi/files/3193/Polttoaineiden_lampoarvot_hyotysuhteet_ja_hiilidioksidin_ominaispaastoer-toimet_seka_energianhinnat_19042010.pdf (15.3.2016)

Mudhoo, A. (2012). Biogas Production: Pretreatment Methods in Anaerobic Digestion (1). Somerset, US, Wiley-Scrivener.

Mutikainen M., Sormunen K., Paavola, H., Haikonen, T., Väisänen, M., Ramboll Finland (2016). Biokaasusta kasvua – Biokaasuliiketoiminnan ekosysteemien mahdollisuudet. Sitran selvityksiä 111, 125p.

Mönkäre, T., Kinnunen, V., Tampio, E., Ervasti, S., Lehtonen, E., Kettunen, R., Rasi, S., Rintala, J. (2016). Ravinnevisio – Selvitys Pirkanmaan puhdistamolietteiden ja biojätteiden ravinteista ja niiden potentiaalisesta käytöstä. Elinkeino-, liikenne- ja ympäristökeskus, raportteja 47/2016. WWW, available: http://urn.fi/URN:ISBN:978-952-314-489-7 (15.8.2016)

Olsson, L. & Fallde, M. (2015). Waste(d) potential: a socio-technical analysis of biogas production and use in Sweden, Journal of Cleaner Production 98, 107-115.

Panwar, N.L., Kaushik, S.C., Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Reviews 15, 3, 1513-1524.

Ravina, M. & Genon, G. (2015). Global and local emissions of a biogas plant considering the production of biomethane as an alternative end-use solution, Journal of Cleaner Production 102, 115-126.

Shafiee, S. & Topal, E. 2009. When will fossil fuel reserves be diminished? Energy Policy 37, 1, 181-189.

Sitra (2016). Biokaasusta kasvavaa liiketoimintaa – liiketoimintaekosysteemien mahdollisuudet – workshops. 8.1. Helsinki, and 29.2. Helsinki.

Smith, A. & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability, Research Policy 41(6), 1025-1036.

Sun, Q., Li, H., Yan, J., Liu, L., Yu, Z., Yu, X. (2015). Selection of appropriate biogas upgrading technology-a review of biogas cleaning, upgrading and utilisation. Renewable and Sustainable Energy Reviews 51, 521-532.

Särkilahti, M., Miettinen, N., Vesa, S., Rahkonen, J., Rintala, J. (2014). Biomaterial management in the future cities Deliverable 3.1.2. Research report no. XX, Cleen Oy, Helsinki

Tilastokeskus (2016). Polttoaineluokitus 2016. WWW, available: http://tilastokeskus.fi/tup/khkinv/khkaasut_polttoaineluokitus.html (23.8.2016)

Tilastokeskus (2015a). Väestöntiheys alueittain 1.1.2015. WWW, available: http://pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin__vrm__vaerak/089_vaerak_tau_132.px/table/tableViewLayout1/?rxid=506266d6-4961-4325-a197-29ba419441d9 (1.4.2016)

Tilastokeskus (2015b). Väestörakenne Suomessa 2015. WWW, available: http://tilastokeskus.fi/tup/suoluk/suoluk_vaesto.html# (18.9.2015)

Tilastokeskus (2013). Moottoriajoneuvokanta 2013. WWW, available: http://tilastokeskus.fi/til/mkan/2013/mkan_2013_2014-03-21_fi.pdf (30.3.2016)

Trafi, 2015. Ajoneuvokanta, mukana vain liikennekäytössä olevat ajoneuvot. WWW, available: http://www.trafi.fi/filebank/a/1453798780/df9ede2b9a607fa5f5adc462e20b888c/19602-liikennekaytossa_olevat_kayttovoimittain_31122015.pdf (21.3.2016)

Tsvetkova, A., Hellström, M., Gustafsson, M., Sjöblom, J. (2015). Replication of industrial ecosystems: the case of a sustainable biogas-for-traffic solution, Journal of Cleaner Production 98, 123-132.

Tähti, H., Rintala, J. (2010). Biometaanin ja –vedyn tuotantopotentiali Suomessa. Jyväskylän yliopisto, Jyväskylän yliopiston bio- ja ympäristötieteiden laitoksen tiedonantoja 90. Jyväskylän yliopistopaino, ISBN 978-951-39-4043-0, Jyväskylä.

Valtioneuvosto (2016). Implementation of the Government Programme. WWW, available: http://valtioneuvosto.fi/en/implementation-of-the-government-programme (1.8.2016)

Wellinger, A., Murphy, J., Baxter, D. (ed.) (2013). The biogas handbook. Science, production and applications. IEA Bioenergy. Woodhead Publishing Ltd. Philadelphia. USA. 508 p.

1260/1996 Laki sähkön ja eräiden polttoaineiden valmisteverosta, Finlex, ajantasainen lainsäädäntö. WWW, available: http://www.finlex.fi/fi/laki/smur/1996/19961260 (23.3.2016)

1281/2003 Ajoneuvoverolaki, Finlex, ajantasainen lainsäädäntö. WWW, available: http://www.finlex.fi/fi/laki/ajantasa/2003/20031281#L2P9 (23.3.2016)

2014/94/EU: Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance. WWW, available: http://data.europa.eu/eli/dir/2014/94/oj (21.3.2016)

30.3.2007/348 Laki julkisista hankinnoista, Finlex, ajantasainen lainsäädäntö. WWW, available: http://www.finlex.fi/fi/laki/ajantasa/2007/20070348 (29.8.2016)

354/2011 Maa- ja metsätalousministeriön asetus rakentamisinvestointien hyväksyttävistä yksikkökustannuksista, Finlex, ajantasainen lainsäädäntö. WWW, available: http://www.finlex.fi/fi/laki/smur/2011/20110354 (23.3.2016)

861/1997 Valtioneuvoston päätös kaatopaikoista, liite 1: Kaatopaikoille asetettavat yleiset vaatimukset liite 3: Kaatopaikan ja sen jälkihoitovaiheen valvonta ja tarkkailu. WWW, available: http://www.finlex.fi/fi/laki/alkup/1997/19970861 (19.2.2016)

APPENDIX A: INTERVIEW STRUCTURE[1]

Warm-up questions:

- Introductions – name and represented actor
- Could you describe your current core activities with a few sentences?
- What kind of role does biogas have in your activities right now? If it is not a part of your current operations, what kind of mental images does biogas awaken in you?

The utopia scenario description: I would ask you to imagine for a moment what an ideal, perfect biogas operation network would look like, in your point of view, and in this location, and what kind of elements it would include. I will give you a few minutes for individual thinking and note-writing. Here in the papers, there are a couple key words to inspire you with the task. Of course, you do not have to write in every category if nothing comes to mind. And there is room for elements that do not fit in any of the categories.

You do not need to think how this scenario could be reached, or is it even realistic. Just try to forget realism for a little while.

Key words:

- Technology
  - Feedstock
  - Gas
  - Digestate
- Collaboration
- Finance
- Other

After the writing part, the ideas written will be discussed. The facilitator will encourage the discussion with probes. If the conversation does not drift to realism naturally, the facilitator could steer it that way. After the discussion, the facilitator will ask if there is anything anyone wants to add to the discussion, or if the interviewees would like to ask something.

[1] Original in Finnish

Backup questions / checklist:

- **What has awoken the initial interest in biogas?**
  - What kind of motivators can be found, and how do they relate to each other?
- **What kind of collaborations have been formed, and how have the actors been chosen?**
  - Are there actors that have not found collaboration partners, even though they have searched for them?
  - Are there actors that would prefer to act alone?
  - Is there need for some kind of forum that brings the actors together?
- **Are you planning to utilize the government subsidies in the process?**
  - How do you feel about the current subsidy structure?
  - How would you improve it?
- **Have you considered other renewable energy production methods alongside biogas production?**
  - If yes, are these considered additional or excluding for biogas?
- **What kind of plans are there for gas utilization?**
  - Were there multiple options?
  - Is there a clientele ready, or is there a challenge to find utilization?
  - If there is a decision made for gas utilization, how was the decision formed?
  - If there is no final decision, has something complicated the decision-making process?
- **Have you considered fluctuation in supply and demand?**
  - How do you plan to guarantee reliability of delivery?
  - What kind of storage capacity do you have for gas?
- **Has the gas infrastructure affected the planning process?**
  - If yes, how?
  - Is there a need to purchase gas from the grid and/or inject gas in the grid?
- **What kind of plans are there for digestate utilization?**
  - If there is a decision made for digestate utilization, how was the decision formed?
  - If there is no final decision, has something complicated the decision-making process?
  - Has the quality of the feedstock affected the digestate utilization?
  - What kind of processing is planned for digestate?
- **How will the gas and digestate be marketed? To whom?**
  - What quality/value do you consider the most prominent selling point?